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THE STUDY OF THE EFFECTS OF FEEDING METHODS AND PROTEIN/LYSINE INTAKE ON LEAN TISSUE GROWTH IN SWINE

BY

DOO-SEOK NAM ©

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND
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DEGREE OF **DOCTOR OF PHILOSOPHY**

IN

ANIMAL NUTRITION

DEPARTMENT OF ANIMAL SCIENCE
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ABSTRACT

Increasing consumer demand for lean meat together with increasing concerns about aspects of health, fitness and environmental pollution has stimulated a research effort to improve the efficiency of lean meat production. One example of such research has been in the development of choice feeding system and the use of diets based on the concept of an ideal protein. The objectives of the five experiments reported in this thesis were to test the hypothesis that pigs are able to select diets to meet their growth potential when they are given a choice of two isoenergetic diets containing different protein level, and to study the performance of pigs fed ideal protein and assigned to different choice feeding systems,

Choice-fed pigs showed a similar growth performance to control pigs but overate dietary protein and required more dietary protein per unit gain of weight. The pattern of diet selection of choice-fed pigs was not influenced by stocking density (number of pigs per pen) and by amino acid balance of diets offered. The addition of feed flavor to the low protein diet did not increase its consumption and choice-fed pigs had a strong preference for the high protein diet over the flavored low protein diet. The increased deposition rate of lean and protein with injection of porcine somatotropin did not stimulate an increase in protein consumption. Pigs fed a conventional diet had better weight gain, feed efficiency and faster lean deposition rate that pigs fed ideal protein based diets

Under the condition of these experiments choice feeding did not appear to be alternative to conventional phase feeding systems due to the increased protein intake but similar growth performance. Feeding ideal protein based diets to growing-finishing pigs did not improve pig performance compared with pigs fed conventional crude protein based diets. It is possible that the protein level of the ideal protein diets were limiting in their supplying of non-essential amino acids.

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I dedicate this thesis to the memory of my late parents for their initial encouragement and support towards my education.

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I. INTRODUCTION

In response to consumer and market demands for lean products, there has been considerable progress over the years in the production of leaner pigs by continuous genetic improvement (Webb. 1990) and constant adaptation of production systems, mainly with regard to feeding strategy, but also in improvements in management and environment. Growing-finishing pigs consume 70 to 75% of the total feed used in commercial pig meat production and for this reason alone their nutritional management and performance are crucial in determining profitability. In the past, we have been satisfied with developing feeding programs and providing diets for "average" requirements, for "average" pigs, under "average" conditions, over one or two feeding periods 20 to 50 kg and 50 to 105 kg (NRC, 1988). However, there is tremendous variability among pigs and feeding conditions within the swine industry and only a relatively small percentage of pigs in the industry are "average". Also, it is known that the pigs requirement for protein and amino acids decline with age in an exponential fashion. There is general agreement that the most profitable feeding program is one based on the formulation of farm specific diets and also diets that change with the age and body weight of the pig. In recent years, two- and four-phase feeding systems have replaced single phase or two phase feeding programs for growing-finishing pigs.

A. THE BIOLOGY OF GROWTH IN PIGS

Growth, a complex and highly integrated process, was defined by Brody (1945) as the production of new biochemical units through metabolic and biologic synthesis. In quantitative terms, growth is the increase in living substance or protoplasm and includes one or more of the following three processes, cell multiplication, cell enlargement, and incorporation of material taken from the environment. The complexity of growth arises because an increase in size and a change in form occur simultaneously within every part of the body. An understanding of accretion of the main tissue types (lean, bone, fat) is important in understanding the essential aspects of growth and the factors affecting carcass composition. From the point of view of pig production, the main interest centres on the development of muscle (lean), and fatty tissue. McMeeken (1940) reported different growth rates for muscle, bone and fat during the development of the pig. Bone and muscle development dominated during the early stage of growth, then rate of growth of these tissues slowed and fat deposition increased. These results were verified by Hiner (1971), Davies (1974), Shields et al (1983), Tess et al (1986) and Gu et al (1992).

Liveweight gain

Black (1986) defined growth as gain in weight brought about by cell multiplication (as in prenatal cleavage) and cell enlargement (as in postnatal muscle growth) and when plotted from conception to maturity is represented by a sigmoid curve (Bridges et al, 1985). Thus, body weight gain can be described as an initial slow growth phase, followed by a rapid growth phase and then a slow growth phase.

Taylor (1978) developed a simple empirical method in which he used age alone to predict body weight. However, such simple models are poor predictors of growth because of the unpredictability of gut-fill (Fisher, 1983). Gut-fill does not have an allometric relationship with empty body weight or indeed with any body component (Hammond, 1932). Several attempts have been made to relate gut-fill to such factors as rate of feed intake, composition of feed and degree of maturity of the animal (Emmans and Fisher, 1986; Kirkwood and Prescott, 1984). Recently, additional factors such as intake of nutrients (Whittemore, 1983), utilization of nutrients consumed (Moughan and Verstegen, 1988), interaction between energy and amino acids (Black et al, 1986) and body DNA (Pomar et al, 1991) have been included to predict the growth of pigs.

Lean tissue gain

Lean tissue growth is the single most important determinant of the nutrient requirement of pigs. Due to its high water (75%) and low fat content (4%), it is energetically approximately 4 times more efficient to deposit lean than fat tissue (ARC, 1981). The capability of the pig to deposit lean is influenced by several factors, primarily genotype (Stahly et al., 1988), sex (Whittemore et al, 1988; Stranks et al, 1988), liveweight (Whittemore et al, 1988), and protein and energy intake (Campbell et al, 1985b). There are well established differences in the rate of lean growth between boars, gilts and barrows. Within any particular genotype, boars are most efficient in depositing lean tissue, followed by gilts, and then barrows (Stranks et al, 1988; Hansen and Lewis, 1993). Barrows generally consume more feed, deposit more fat, and are often less efficient when compared with gilts (Cromwell et al, 1993).

The observed lean growth rate of commercial pigs may be lower than the actual potential of the pigs due to factors limiting the expression of the lean growth potential. In order to feed pigs for maximization of lean deposition, genotype and sex differences need to be taken into consideration in feeding strategies. Previous studies (Schinckel, 1993) have indicated a need for increased dietary nutrient input for pigs with a high potential for lean growth.

Fatty tissue growth

Fat is an essential tissue in pigs and provides a buffer against variations in nutrient supply. It is the latest maturing of all the tissues and it may continue to be deposited long after growth in the other tissues has ceased. However, in the pig fat has a special role in that it also supplies insulation, particularly in the newborn pig. Whilst there is less than 2% fat in a pig at birth, by 21 days of age there is usually more than 15% (Manners and McCrea, 1963; Wood and Groves, 1965; Whittemore et al, 1978). Modern pigs may never again be fatter than they are at 21 or 28 days of age, at the time of weaning. In this respect, therefore, the pig is somewhat of an anomaly in relation to other species.

Control of body fatness in modern pig strains is primarily a function of weight and feed intake. Whittemore (1993) suggested that the following conditions are those that will allow fattening to occur: 1) when the diet is imbalanced (at any pig weight); 2) when feed intake exceeds the needs of maintenance and lean tissue growth (at any pig weight); 3) when the body places fat accretion above lean accretion in its order of priority. This may occur postnatally between birth and weaning, or during pregnancy when preparing for lactation, or in expectation of times of feed shortage. It is helpful to differentiate total body lipid into three components: essential fat, target fat and surplus or depot fat. A minimum level of fat is essential to normal metabolic function; this is probably about 5% lipid in the whole body. It has been suggested that lean tissue deposition must be accompanied by the deposition of a certain level of fat. This fat level has been called target fat (Whittemore, 1993). Energy surplus to that required for maintenance, lean tissue growth, essential and target fat is deposited as depot fat. This surplus or depot fat is therefore a means of either dealing with surplus energy in feed or creating a depot of potential energy in the body.

B. FACTORS AFFECTING GROWTH

Knowledge of the factors influencing lean growth rate is crucial for the design of diets and feeding strategies to achieve more efficient pig production. In the majority of situations the most efficient and profitable feeding strategy is that which most closely matches the nutrient intake of the pig to its capacity for lean growth. To achieve this efficiency requires a knowledge of the pigs feed intake and its lean tissue growth rate. In addition, this efficiency will only be achieved if the factors affecting nutrient utilization are also known. Among such factors are energy and protein ratio and amino acid balance and availability.

Energy-protein interaction in pigs

It is well established that protein deposition can be constrained by an inadequate intake of either protein or energy or both (Black and Griffiths, 1975). However, it is less well understood that these two inputs exert their effects on protein deposition through separate and independent mechanisms, giving rise to the concept of protein- and energy-dependent phases of lean tissue growth (Campbell et al, 1984).

Under conditions of dietary protein deficiency, lean tissue growth can be increased by raising the dietary protein level or by increasing feed intake. However, in both cases the response is related to the associated increase in protein intake. The rate of improvement in protein accretion per unit increase in protein intake is directly related to the digestibility and biological value of the dietary protein (Black and Griffiths, 1975; Campbell and Dunkin, 1983a and b), but independent of the inherent potential of the animal for lean growth.

Under conditions of protein adequacy, quantitative information is required as to the relationship between liveweight and potential protein and energy accretion rates. There is limited support in the literature for each of two alternative response relationships between energy intake and protein deposition, namely linear and linear-plateau. The linear model proposes that lean tissue growth is constrained primarily by energy intake and is supported by the results of experiments with lambs (Black and Griffiths, 1975) and broiler chickens (Leclercq and Saadoun, 1982). The ARC (1981) also adopted the linear model to describe the relationship between energy intake and protein deposition for growing pigs.

In contrast, Whittemore and Fawcett (1976) proposed a linear-plateau relationship between energy intake and protein deposition This model suggests that pigs respond linearly to increasing energy intake until a maximum is attained at which point the response plateaus. During the earlier stage of development (up to 50 kg), rate of protein deposition increases linearly with an increase in feed intake up to the limit of the animals's appetite (Campbell, 1985a). The difference between the sexes is generally small but increases with liveweight (Campbell et al, 1988a). Above 50 kg, the genetic potential for protein deposition of pigs tends to lie within the limits of appetite (Campbell et al, 1985b); Dunkin et al, 1986; Dunkin and Black 1987).

Recently, Kyriazakis and Emmans (1992a and b) supported the linear-plateau relationship by testing four different models to describe protein and lipid retention with varying energy and protein intake. This linear-plateau relationship between protein deposition and protein and energy intake can be expressed as two phases: (i) an initial protein dependent phase in which when pigs of a given body weight are fed increasing amounts of protein, of a constant quality, in conjunction with a set amount of energy, protein deposition increases linearly until a maximum value is reached at a particular level of protein intake. Additional increments of protein will not produce any further rise in protein deposition and (ii) an energy dependent phase in which additional protein is deposited at a higher protein intake only when energy intake is increased. Thus, protein deposition is unaffected by energy intake when protein intake is limiting and conversely, is driven by energy intake when dietary protein supply is equal to or above requirement.

Ideal protein

In attempts to match nutritional inputs as closely as possible to the potential of the animal, other attributes of amino acid needs of pigs should be considered. As a result of increased usage of alternative protein sources, including synthetic amino acids, at competitive prices, the increased knowledge of the negative aspects of excessive dietary protein intake on environmental pollution, and profitability in pig production is vital. Thus, application of the concept of an ideal protein is becoming increasingly important in swine diet formulation.

The concept of an ideal protein is not new. In the 1940s, scientists tried to relate the amino acid composition of proteins to their nutritive value by using terms such as chemical score (Block and Mitchell, 1946) or complete protein (Howard et al, 1958). Block and Bolling (1944) noted that proteins of high nutritional value tend to resemble, in their amino acid composition, the tissue of the animals consuming them. The importance of body protein deposited during growth led to the concept that the amino acid requirements of growing animals are determined primarily by the amino acid composition of body tissue protein formed. The concept of an ideal protein was coined by Cole (1978) and used by ARC (1981) to establish the protein requirements of pigs. An ideal protein is one that supplies amino acids in the same ratio at the tissue level that in which they are required by the pig. The profile of amino acids contained in an ideal protein is therefore similar to that in pig lean tissue and sow milk and is represented as a ratio of the level of each essential amino acid relative to that of lysine (ARC, 1981).

The use of lysine as the reference amino acid was derived from the review of ARC (1967). It has been suggested that variation in the estimates of the requirement of a particular amino acid were reduced if the requirement was expressed relative to lysine. The concentration of lysine is assumed to be 7.0 g lysine/ g protein. However, NRC (1988) selected tryptophan as the reference amino acid in the development of an ideal amino acid pattern. One of the values of the ideal protein concept is that it allows the complete amino acid requirements of the pig to be expressed as one variable; i.e. 'ideal protein'.

After the concept of an ideal protein was introduced by ARC (1981), several studies were conducted to determine the 'ideal' balance of available amino acids required at the tissue level to obtain maximum amino acid utilization (Fuller et al, 1983; Moughan and Smith, 1984; NRC, 1988; Wang and Fuller, 1989; Fuller et al, 1989; Chung and Baker, 1992). There is some disagreement as to the actual ratios of the amino acid in an ideal protein as can be seen from the data in Table I. 1. The amino acid ratios in an ideal protein as presented in Table I. 1 were originally thought to apply to pigs of all body weight. If one considers that the amount of each amino acid required for the deposition of one gram of lean tissue is the same for any weight of pig, then the amount of protein required by animals of different weight would vary according to their lean tissue growth rate. Thus, pigs of different genetic potential for protein deposition or of similar genetics but raised under different environmental conditions should only require different amounts of an ideal protein. However, as the rate of protein deposition declines, the amino acid requirements for maintenance become a larger portion of the total, and this may result in an alternation of the pattern of amino acids constituting an ideal protein.

Thus, the concept of an ideal protein has recently been expanded to distinguish between amino acid ratios for maintenance and those required for protein deposition (Fuller et al, 1989). The estimates of the ideal amino acid balance required for protein deposition are quite similar to the amino acid composition of body tissue, but for maintenance there are slightly higher requirements for threonine and for methionine + cystine, amino acids which are represented in more than average amounts in endogenous protein losses. Considering the difference in the amino acid composition of body proteins, such as myofibrilar proteins and collagen, it is reasonable to expect that amino acid patterns may be different in pigs at different growth stages. Lopez et al (1994) reported that weight gain, feed intake and feed efficiency were similar for gilts fed conventional diets based on crude protein and those fed diets based on ideal protein. Recently Batterham et al (1990) and Moughan et al (1987) suggested that the amino acid profile in ideal protein changes according to growth stage. Black and Davies (1991) confirmed the composition of an ideal protein change with an increase in body weight and suggested that threonine to lysine ratio increased as body weight increased and also increased with an increase in the fiber content of the diet.

With the wide range of feed ingredients being used in pig feeding and the desire for greater precision and efficiency in meeting amino acid requirements at tissue level, Fuller and Wang (1989) suggest that it is essential to express the amino acid balance of the ideal protein in terms of digestible amino acid rather than total amino acids when formulating practical diets.

C. FEEDING SYSTEM

In developing a feeding strategy to improve production efficiency and to meet the considerable variation in growth rate and lean growth potential that occurs under commercial conditions, additional factors should be considered in addition to energy protein ratio and amino acid balance. Feeding system is a~other factor affecting production efficiency. Though a unique feeding program designed for the specific circumstances of each farm simply are not practical, much efforts should be made to match the diet to the pigs nutrient requirement as closely as possible.

From 20 kg BW to market weight, a pig's nutrient requirement will decrease with an increase in age and BW. In most commercial swine units, it is not possible to change the composition of a diet on a daily basis to meet the changing nutrient requirements of the pig. Some pig producers use a single phase feeding program which involves feeding only one diet from 20 kg BW to market weight. This feeding regimen will result in over-feeding protein for a considerable amount of the growing-finishing period and thus is seldom economical. Though a single feeding system removes the cost of installing several feeder bins, benefits of this feeding system are seldom viable compared to a conventional phase feeding system.

Phase feeding

Pig producers usually use a conventional phase feeding program which provided a specific diet to pigs during the certain stages of the pigs life cycle. The number of phases used from 20 kg

BW to market weight depends on market conditions, farm facilities, feeding strategy, and availability of labour. Traditionally, producers used a two or three phase feeding system for growing-finishing pigs from 20 to 110 kg BW. NRC (1988) suggested a two phase feeding program, 20 to 50 and 50 to 100 kg BW.

Changing the protein levels of the pig diets several times during the growing-finishing period should reduce the chances of under- and over-feeding nutrients and, in theory, should result in better overall performance and reduced feed cost. Bradford and Gous (1991b) have recently confirmed that as the number of diets used increased, protein intake per gain decreased. But phase feeding requires the availability of a number of bins for the different diets and perhaps extra labour.

Choice feeding (diet self selection)

It is commonly observed, even in genetically similar pigs, that there are considerable differences in growth performance of pigs between farms, in different barns within farms, in different pens and even between different pigs within the same pen. Also, the requirement of growing pigs for protein changes continuously as they grow. Therefore, conventional feeding systems, such as two or three phase feeding, in which pigs are given free and continuous access to a single feed for a period of time cannot meet the wide range in individual variation nor can they easily satisfy the changes in the pigs' nutrient requirements over time and increasing body weight.

An alternative way to cater to individual variation in the nutrient requirement of pigs reared in groups is to give pigs the opportunity of selecting diets to meet their requirements (choice feeding). Choice feeding systems provide pigs with a choice of two isoenergetic diets differing in protein content so that they can select a protein intake level to meet their requirements. A choice feeding system was first described by Stabler (1911) and Evvard (1915 a, b). They demonstrated that as pigs grew, they maintained a balance between protein and energy intake by changing the proportion of each of several feeds they selected, when they were offered ad libitum access to a wide range of feeds. Later, Morrision (1937) also offered additional evidence of the pigs ability to balance their diets when they were offered a choice between a cereal (corn or wheat) and a protein supplement (tankage). Pigs consumed enough supplement to balance their diet and gradually chose smaller proportions of the supplement as they grew older. In another experiment, in which pigs were given a choice of a protein-free diet and a diet deficient in one amino acid (Robinson, 1974; 1975) or a choice between a complete diet and one deficient in a single amino acid (Devilat et al, 1970; Davey, 1978), the pigs avoided the deficient diet and consumed only the protein-free diet or the complete diet.

More recently it has been reported that individually housed pigs can differentiate between diets of different protein levels and tend to select a protein intake level to meet their requirements (Kyriazakis 1989; Kyriazakis et al. 1990 and 1991). These observations were supported by the results of Bradford and Gous (1991b) who also suggested that choice feeding appears to have more potential for commercial swine operations than does phase feeding. In contrast, Owen et al (1994) reported that growing-finishing pigs do not have the ability to select the correct proportions of each diet to optimize performance and carcass leanness when offered a choice of low- and high-lysine sorghum-soybean meal diets. Gourley et al (1993) also reported that choice-fed pigs consumed more protein (lysine) during the finisher period than phase-fed pigs. Other recent findings (Gill et al, 1994; Cromwell et al, 1994) also suggest that choice feeding may be a suitable system for cost-effective growing-finishing pig production as a result of an increased protein intake compared to conventional single-fed pigs.

If pigs can control their protein intake to meet their requirement, choice feeding has obvious advantages over conventional phase feeding systems because it may allow better expression of the pigs growth potential. Before adopting the choice feeding system into commercial pig production, the relative potential of choice feeding should be further evaluated.

D. OBJECTIVES OF RESEARCH

Based on the issues addressed in this introduction, the objectives of the research carried out for this thesis were as follows:

1. To evaluate the potential of choice feeding systems in pig production.
2. To determine whether it is necessary to change the protein levels in a choice feeding system to match the pigs' declining protein requirement as they increase in body weight.
3. To determine whether pigs have the ability to select a lysine intake to meet their requirement when offered a choice of two isoenergetic and isonitrogenous diets differing in lysine levels.
4. To determine whether amino acid supplementation influences the pattern of diet selection of choice-fed pigs.
5. To determine whether enhanced lean growth of somatotropin treated pigs would result in increased intake of the high protein diet to meet the enhanced lean growth.
6. To determine the effects of addition of feed flavour to the low protein diet, and stocking density within a pen on diet selection in choice-fed growing-finishing pigs.
7. To investigate the potential of ideal protein based diets in a conventional feeding system.

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Table I. 1. Amino acid composition of ideal protein pattern, expressed relative to lysine[1]

Amino acids	ARC (1981)	NRC (1988)	Wang and Fuller (1990)	Chung and Baker[2] (1993)
	% of lysine			
Arginine	n.d[3]	33	n.d	42
Lysine	100	100	100	100
Histidine	33	29	n.d	32
Isoleucine	54	61	60	60
Leucine	100	80	111	100
Methionine + cystine	50	57	61	60
Phenylalanine + tyrosine	99	88	120	95
Threonine	60	64	64	65
Tryptophan	14	15	20	18
Valine	70	64	75	68

[1] requirements listed for 20 - 50 kg pigs.

[2] Pattern for 10 kg pigs.

[3] Not determined

II. A COMPARISON OF CHOICE AND PHASE FEEDING FOR GROWING-FINISHING PIGS[1]

A. INTRODUCTION

It is commonly observed, even in genetically similar pigs, that there are considerable differences in growth of pigs between farms, in different barns within farms, in different pens and even between different pigs within the same pen. Also, the requirement of growing pigs for protein changes continuously as they grow. Therefore, conventional feeding systems, such as two or three phase feeding, in which pigs are given free and continuous access to a single feed for a period of time cannot meet the wide range in individual variation nor can they easily satisfy the changes in the pigs' nutrient requirements over time and increasing body weight.

An alternative feeding system, choice feeding, could be considered, which provides pigs with a choice of two isoenergetic diets differing in protein content so that they can select a protein intake to meet their requirements (Devilat et al. 1970; Davey 1978). If pigs can control their protein intake to meet their requirement, choice feeding has obvious advantages over conventional phase feeding systems because it may allow better expression of the pigs growth potential. It has recently been reported that individually housed pigs can differentiate between diets of different protein levels and tend to select a protein intake level to meet their requirements (Kyriazakis 1989; Kyriazakis et al. 1990). These observations were supported by the results of Bradford and Gous (1991b) who also suggested that choice feeding appears to have more potential for commercial swine operations than does phase feeding. In contrast, Owen et al (1994) reported that growing-finishing pigs do not have the ability to select the correct proportions of each diet to optimize performance and carcass leanness when offered a choice of low- and high-lysine, sorghum-soybean meal diets. Our previous results (Nam et al. unpublished observation) indicated that the pattern of protein selected by choice-fed pigs did not change with an increase of weight and age in pigs. Gourley et al (1993) reported that choice-fed pigs consumed more protein (lysine) during the finisher period than phased-fed pigs. Thus, before recommending a choice feeding system to commercial pig producers, more information is required to evaluate its potential.

Thus, the objectives of the present experiment were 1) to determine whether pigs, when housed in groups, can satisfy their protein requirements when offered a pair of diets differing in protein content, and 2) to determine whether it is necessary to change the protein levels in the choice feeding system to match the pigs' declining protein requirement as they increase in body weight.

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[1] A version of this chapter has been accepted for publication. Nam, D. S. and Aherne, F. X. 1994. Can. J. Anim. Sci.

B. MATERIALS AND METHODS.

Animals and facility

Seventy-two gilts (Landrace x Yorkshire), of an average initial body weight of 19.7 kg, were allotted in groups of three to each of 24 (1.2 x 2.3 m) totally slatted floor pens. Room temperature was maintained at 20 to 22°C during the first 4 weeks, and 17 to 20°C thereafter. Equal numbers of pens were assigned to each of the four treatments. Dietary treatments consisted of 1) conventional three phase feeding (18-16-14% crude protein ; **P3**), 2) one phase feeding (16% ; **P1**), 3) three phase choice feeding using two diets differing in protein level (24/14, 22/12, 20/10% ; **C3**), and 4) one phase choice feeding (24/10% throughout; **C1**). The three growth phases were 20 to 50, 50 to 70, and 70 to 105 kg live weight. Feed and water were available at all times during the trial. To accustom pigs to the diets, choice-fed pigs were allowed access to each diet on alternate days for 7 days prior to the commencement of the experiment as suggested by Kyriazakis (1989). Within each pen, choice-fed pigs had access to two single-hole feeders and pigs assigned to the phase feeding regimens had access to one two-hole feeder, but the space allowed each animal was the same. The position of the feeders within pens assigned to choice feeding was not changed throughout the experiment, as it has been reported that feeder position does not affect diet selection in pigs (Kyriazakis 1989). The position of the two feeders, however, was randomized across pens. Individual pig's weight gain and pen-based feed intake were recorded weekly.

Diets

All diets were based on barley and soybean meal, formulated to contain 13.7 MJ DE kg^{-1} and provided sufficient vitamins and minerals to meet the pig's requirement for growth (NRC 1988). The composition of the experimental diets is presented in Table II.1. The low and high protein diets used in the choice feeding system were formulated to be below and above the pig's requirement (NRC 1988), respectively. The high protein diet contained more macrominerals to maintain suitable ratios to protein. The ratio of lysine to protein was also fixed in all diets. Diets were assayed for crude protein by the Kjeldahl method (AOAC, 1990). Separation and quantification of lysine was accomplished with a High Performance Liquid Chromatography (Varian 5000, Varian Associates Inc., Walnut Creek, CA 94598) and a Varian Fluorichrom detector (excitation 340 nm, emission 450 nm). Each sample (0.1 g) was hydrolyzed with 3 mL of 6N HCl for 24 hr at 110°C. Samples were mixed 1:1 with the fluoraldehyde reagent prior to injection, then 25 μL of mixed sample was injected onto a Supelocosil 3 micron LC-18 reverse phase column (4.6 x 150 mm; Supelco, Oakville, ON).

Carcass data collection

When pigs reached 105 kg, they were sent to a commercial processing plant for slaughter. Fat depth and muscle depth were measured between the 9 and 10th last ribs, 70 mm from the carcass mid-line, by Hennessy Grade Probe (Hennessy and Chong Ltd., New Zealand) and these measurements were used to predict carcass lean content. Lean yield was estimated using the following equation (Agriculture Canada 1986); Lean yield = 54.31 - 0.36 (Fat depth, mm) + 0.06 (Muscle depth, mm).

Statistical analysis

All data were analyzed by ANOVA using the GLM procedure appropriate for randomized block design (SAS 1985). Means of each treatment were compared using the Student-Newman-Keuls test for each variable. When initial weight and carcass weight were noted to be significant ($P<0.05$) in the model, initial body weight and carcass weight were used as covariates for analysis of growth performance and carcass measurements. Each pen was considered as an experimental unit.

C. RESULTS

Growth performance

According to the pooled result within phase and choice feeding, from 20 to 50 kg body weight (BW) (Period one), pigs assigned to a choice feeding regimen had superior ($P < 0.05$) growth rate (793 vs 713 g d^{-1}) and larger ($P < 0.05$) feed intake (1.467 vs 1.368 kg d^{-1}) with no significant difference in feed:gain (1.85 vs 1.95) compared with phase-fed pigs. During period two (50 to 70 kg BW), feed intake decreased ($P < 0.05$) and feed efficiency was improved ($P < 0.05$) for choice-fed pigs compared with phase-fed pigs. Through the entire period (20 to 105 kg BW), phase feeding resulted in decreased ($P < 0.05$) feed intake (2.32 vs 2.49 kg d^{-1}) and improved ($P < 0.05$) feed efficiency (2.74 vs 2.89; feed/gain) with no significant difference in weight gain (850 vs 861 g d^{-1}) compared with choice feeding.

Performance data are presented in Table II.2. Pigs fed a 16% crude protein diet (**P1**) showed the poorest weight gain (695 g d^{-1}) and feed efficiency (2.02) during period one (20 to 50 kg BW). Also in period one, **C3** pigs had significantly superior growth rate to pigs in **P1** or **P3** (801 vs 695 or 731 g d^{-1}) and **C1** and **C3** pigs had similar weight gain, feed intake and feed efficiency. From 50 to 70 and 70 to 105kg BW, there were no significant treatment effects on weight gain, feed intake or feed to gain ratio. However, from 70 to 105 kg, pigs fed 16% CP (**P1**) showed numerically greater growth rate (939 g d^{-1}), feed intake (3.14 kg d^{-1}) and feed efficiency (3.36) than all other treatment groups. During the overall period (20 to 105 kg BW), there were no significant treatment differences in weight gain and feed to gain ratio. Feed intake of the **C3** pigs was greater

($P < 0.05$) than that of **P3** pigs.

Protein selection

Protein intake, and protein efficiency (**PE**: g of protein intake/kg of weight gain) are shown in Table II.3. Protein intake was increased ($P < 0.05$) by choice feeding compared with phase feeding during period one and two. As a result of the increased protein intake, choice-fed pigs required ($P < 0.05$) more dietary protein per unit weight gain than phase-fed pigs. From 70 to 105 kg BW (Period 3), there was no significant difference in protein intake between choice and phase feeding. However, more ($P < 0.05$) dietary protein (574 vs 491 g d^{-1}) was required for weight gain (kg) in choice-fed pigs than phase-fed pigs. Over the entire study, as a result of an increased protein intake by choice-fed pigs, the **PE** value was increased ($P < 0.05$) compared with phased-fed pigs (493 vs 427 g d^{-1}).

There were no significant differences in protein intake between both choice feeding treatments or between both phase feeding treatments for period one, two and the overall experiment. Protein intake of pigs fed 16% protein (**P1**) was higher ($P < 0.05$) than that of **P3** pigs fed 14% protein (482 vs 392 g d^{-1}) during period three. Pigs fed the 14% protein diet consumed the least amount of protein (392 g d^{-1}) and had a superior **PE** than all other treatment groups. Values for **PE** were not significantly different between both phase feeding or between both choice feeding regimens. However, pigs in **C3** showed a higher ($P < 0.10$) PE value than pigs in **C1** during period three and the overall experiment.

As shown in Figure II.1B, crude protein content of diets selected did not differ significantly between **C1** and **C3** pigs for any period or for the overall experiment. There was, however, some difference ($P < 0.05$) between choice-fed pigs in the proportion of high protein diet selected (Figure II.1A). Pigs in **C1** showed a strong initial preference for the high protein diet (81.9% of total feed intake) compared with **C3** pigs which selected 68.1% of total feed intake as the high protein diet. During period two, the proportion of the high protein diet selected by **C1** and **C3** pigs was 53.4 and 57.7%, respectively. Pigs in **C1,** during period 3, selected 39.6% of total feed intake as the high protein diet compared with the 69.3% for the **C3** pigs. Over the entire trial, **C1** pigs showed an equal preference for the high and low protein diets and **C3** pigs consumed more ($P<0.05$) of the high protein diet (64.9% of total feed intake). These changes in the proportion of the high protein diet consumed resulted in a change in the protein content of the diets selected over time (Figure II.1B). For both choice-fed pigs (**C1** and **C3)**, the protein content of the selected diet declined with an increase in body weight. The protein content of selected diets for **C1** and **C3** pigs were 21.53 and 21.05, 17.50 and 17.72, 15.58 and 16.89, and 16.82 and 17.31% for period one, two, three and overall period, respectively. There were no significant differences in protein content of the selected diet between both choice-fed groups. However, the protein level in the selected diets for both choice-fed pigs were higher ($P < 0.05$) than that in diets consumed by phased-fed pigs for each weight interval.

Carcass measurements

There was a significant difference ($P < 0.05$) in carcass dressing percentage, between choice- and phased-fed pigs (Table II.4). Pigs in **C3** had the highest ($P < 0.05$) dressing percentage (80.79%) compared with those in other feeding regimens. Pigs in **C3** and **P3** had lower ($P < 0.10$) carcass grade index and lean depth than pigs in **P1** and **C1**.

D. DISCUSSION

The objective of the present trial was to evaluate the effectiveness of different pig feeding systems by determining whether pigs can control their protein intake to meet their requirement when given a choice between two isoenergetic diets containing high and low protein levels. While, weight gain and carcass characteristics of choice-fed pigs were comparable with those of phased-fed pigs (Table II.2 and 4), choice-fed pigs consumed significantly more dietary protein due to a strong preference for the high protein diet (Figure II.1A) and not from an increase in total feed intake (Table II.2). Also, the protein content of diets selected by choice-fed pigs was higher than that in diets consumed by phased-fed pigs (Figure II.1B). These observations suggest that pigs do not have the ability to accurately select a protein intake to meet their protein requirement when offered a choice of diets differing in protein content. This increased protein intake by choice-fed pigs in the present study was not observed by Kyriazakis (1989) or Bradford and Gous (1991a and 1992) who reported that choice-fed pigs showed a similar protein intake to single-fed pigs.

On other hand, recent results of Owen et al (1994) support the present observation. Gourley et al (1993) also observed that the lysine intake of choice-fed pigs was similar during the grower period but higher during the finisher period compared with phased-fed pigs. As suggested by Emmans and Fisher (1986), this preference for the high protein diet may be a result of differences in relative palatability of such diets. The amount of soybean meal used in the 24% and 10% crude protein diets in the present trial were 40.1 and 2.6%, respectively (Table II.1) and may have made the high protein diet more palatable than the low protein diet. Protein source and diet composition may also contribute to the discrepancy in results between the current trial and those of others (Kyriazakis et al, 1990; Bradford and Gous 1991a and b). Kyriazakis et al (1990) included molasses and milk replacer in the experimental diets and Bradford and Gous (1991a and b) used fish meal as a protein source.

The proportion of high protein diet selected by choice-fed pigs differed significantly between 70 and 105 kg. The **C3** pigs increased their intake of the high protein diet whereas the **C1** pigs continued to reduce the proportion of high protein diet selected. This pattern of diet selection suggests that pigs select a majority of a diet which is nearest in nutrient content to their requirements, a suggestion supported by the data of Kyriazakis et al (1990).

Pigs in **P1** performed as well as pigs raised on other dietary treatments and showed better **PE** than choice-fed pigs. Also these pigs had similar carcass characteristics to pigs in other dietary treatments. Growth rate of **P1** pigs in period three (939 g d^{-1}) was sufficient to compensate for the reduced growth in period one and suggests compensatory growth occurred (Mersmann et al, 1987).

Difference in protein intake between single and choice-fed pigs were not reflected in carcass lean content (Table II.4). These results are in agreements with those of Gourley et al (1993). Bradford and Gous (1991a) reported that choice-fed pigs had less backfat than single-fed pigs and Owen et al (1994) showed the percentage of lean in choice-fed pigs to be lower than that of single-fed pigs.

Overall protein intake in **P3** pigs was 345 g d^{-1}, 35 g less than that of P1 pigs. The **P3** pigs can save 3.5 kg (0.035 kg x 100 day) of dietary protein during growing-finishing period. This saving in dietary protein is equivalent to 7 kg soybean meal containing 47% of crude protein, a $ 2 increase per marketed pigs when soybean meal costs $ 360 per tonne.

In conclusion, pigs did not have the ability to select a protein intake to meet their requirements when provided a choice of isoenergetic diets differing in protein content. The results of the present experiment and those of Owen et al (1994) suggest that overconsumption of protein by choice-fed pigs would make the adoption of a choice feeding system uneconomical under commercial conditions.

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Table II. 1. Composition of the experimental diets

Crude Protein, %	24	22	20	18	16	14	12	10
Ingredients ($g\ kg^{-1}$)								
Barley	525	578	630	682	732.5	787	837	889
Soybean meal (48% CP)	401	348	293	240	187	132	80	26.45
Tallow	29	31	34	37	40	42	45	48
Limestone	12	11	11	11	10	10	9	9
Dicalcium-phosphate	19	18	17	15	15	13	13	11
Salt	4	4	4	4	4	4	4	4
Vitamin-mineral Premix[1]	10	10	10	10	10	10	10	10
Lysine-HCl	-	-	1	1	1.5	2	2	2.5
Threonine	-	-	-	-	-	-	-	0.05
Nutrients (As fed basis)								
DE[2], MJ/kg	13.70	13.70	13.70	13.70	13.70	13.70	13.70	13.70
Protein, %	23.99	22.00	19.99	17.99	16.01	13.99	12.02	10.02
Lysine, %	1.39	1.25	1.18	1.04	0.93	0.83	0.69	0.58
Methionine + Cystine[2], %	0.72	0.67	0.61	0.56	0.51	0.46	0.41	0.36
Threonine[2], %	0.88	0.80	0.72	0.64	0.56	0.47	0.40	0.36
Calcium[2], %	0.92	0.86	0.83	0.78	0.73	0.69	0.64	0.59
Phosphorus[2], %	0.84	0.81	0.77	0.71	0.69	0.63	0.62	0.56

[1] Vitamin mineral premix supplied the following per kg of diet: 5,000 IU vitamin A, 500 IU vitamin D, 40 mg vitamin E, 30 µg vitamin B_{12}, 12 mg riboflavin, 45 mg niacin, 25 mg pantothenic acid, 300 mg choline, 5 mg Ethoxyquin, 150 mg Fe, 20 mg Mn, 120 mg Zn, 20 mg I, 20 mg Cu, 0.3 mg Se.

[2] Calculated value

Table II. 2. Performance of phase- and choice-fed pigs

Body weight	Feeding systems[1]				SEM[2]
	P1	P3	C1	C3	
	16	18-16-14	24/10	24/10-22/12-20-10	
Period 1 (20-50 kg)					
Weight Gain, g/d	695^{c}	731^{bc}	785^{ab}	801^{a}	19.4
Feed Intake, kg/d	1.40^{ab}	1.33^{b}	1.41^{ab}	1.52^{a}	0.04
Feed/Gain, kg/kg	2.02^{a}	1.83^{b}	1.89^{b}	1.91^{ab}	0.05
Period 2 (50-70 kg)					
Weight Gain, g/d	890	884	914	942	28.8
Feed Intake, kg/d	2.23	2.22	2.44	2.52	0.25
Feed/Gain, kg/kg	2.51	2.52	2.67	2.68	0.07
Period 3 (70-105 kg)					
Weight Gain, g/d	939	840	821	846	33.6
Feed Intake, kg/d	3.14	2.82	2.88	3.00	0.11
Feed/Gain, kg/kg	3.36	3.37	3.53	3.57	0.16
Overall (20-105 kg)					
Weight Gain, g/d	868	832	854	868	20.8
Feed Intake, kg/d	2.38^{ab}	2.27^{b}	2.43^{ab}	2.55^{a}	0.07
Feed/Gain, kg/kg	2.74	2.73	2.84	2.94	0.07

[1] P1:One phase 16% crude protein diet throughout trial.

P3:Conventional three phase feeding 18-16-14% for each weight interval.

C1:One phase choice feeding (24/10%) throughout trial.

C3:Three phase choice feeding 24/14, 22/12, and 20/10% for each weight interval.

[2] Pooled standard error of the mean.

[a, b, c] Means within a row with a different superscript letter differ, $P < 0.05$.

Table II. 3. Dietary protein intake and utilization for weight gain in phase- and choice-fed pigs

Body weight	Feeding systems[1]				SEM[2]
	P1	P3	C1	C3	
	16	18-16-14	24/10	24/14-22/12-20/10	
Period 1 (20-50 kg)					
Protein Intake, PI, g/d	227^{b}	243^{b}	303^{a}	320^{a}	7.08
PI/Gain, g/kg	326^{b}	334^{b}	387^{a}	400^{a}	6.83
Period 2 (50-70 kg)					
Protein Intake, PI, g/d	357^{b}	354^{b}	426^{a}	448^{a}	17.6
PI/Gain, g/kg	402^{b}	400^{b}	464^{a}	474^{a}	11.5
Period 3 (70-105 kg)					
Protein Intake, PI, g/d	482^{a}	392^{b}	448^{ab}	507^{a}	21.3
PI/Gain, g/kg	515^{bc}	468^{c}	547^{a}	601^{a}	22.7
Overall (20-105 kg)					
Protein Intake, PI, g/d	380^{bc}	345^{c}	408^{ab}	441^{a}	13.1
PI/Gain, g/kg	439^{b}	415^{b}	477^{a}	508^{a}	12.1

[1] P1:One phase 16% crude protein diet throughout trial.

P3:Conventional three phase feeding 18-16-14% for each weight interval.

C1:One phase choice feeding (24/10%) throughout trial.

C3:Three phase choice feeding 24/14, 22/12, and 20/10% for each weight interval.

[2] Pooled standard error of the mean.

[a, b, c] Means within a row with a different superscript letter differ, $P < 0.05$.

Table II. 4. Carcass measurements of phase- and choice-fed pigs

Items	Feeding systems[1]				SEM[2]
	P1	P3	C1	C3	
	16	18-16-14	24/10	24/14-22/12-20/10	
Carcass Weight, kg	80.40	80.02	81.69	81.68	0.89
Dressing Percentage	79.01^a	79.48^a	79.37^a	80.79^b	0.35
Hennessy Probe					
Lean Depth, mm	45.20	49.14	48.96	46.57	3.51
Fat Depth, mm	14.34	15.54	15.04	15.93	0.88
Grade Index	109.14	109.23	109.33	108.00	0.66
Lean Yield, %	51.81	51.62	51.78	51.31	0.15

[1] P1:One phase 16% crude protein diet throughout trial.

P3:Conventional three phase feeding 18-16-14% for each weight interval.

C1:One phase choice feeding (24/10%) throughout trial.

C3:Three phase choice feeding 24/14, 22/12, and 20/10% for each weight interval.

[2] Pooled standard error the mean.

[a, b] Means within a row with a different superscript letter differ, $P < 0.05$.

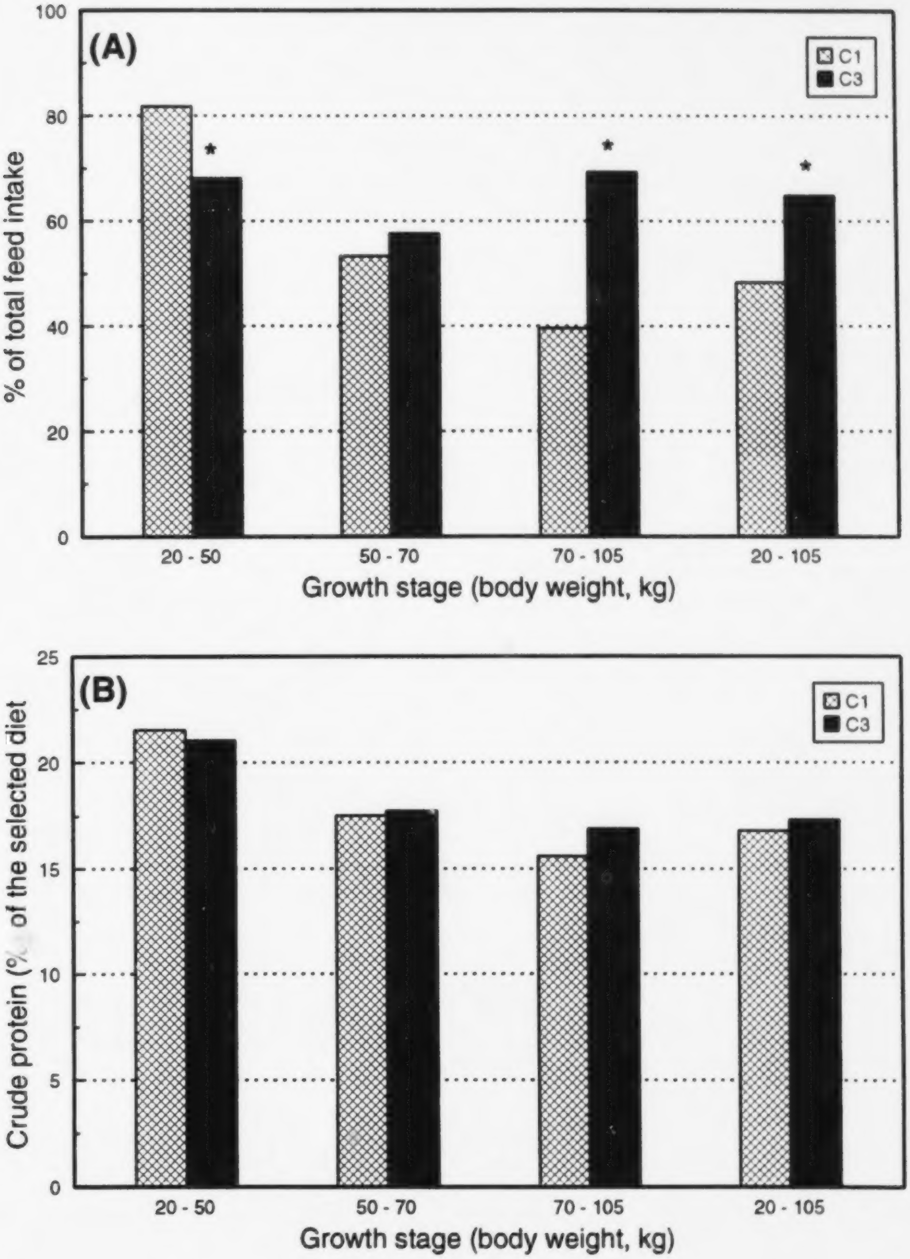

Figure II. 1. The proportion (%) of the high protein diet/total intake (A) and the percentage of crude protein in the selected diet (B) for choice-fed pigs given free access to high and low protein diets (**C1**: 24/10% throughout trial; **C3**: 24/14, 22/12, and 20/10% for each stage, respectively). HP: High protein; *:represents a significant difference, P<0.05 within each stage).

III. THE EFFECTS OF AMINO ACID(S) SUPPLEMENTATION ON DIET SELECTION BY GROWING PIGS[1]

A. INTRODUCTION

To improve the productivity and profitability of swine production, several attempts have been made to reduce dietary protein usage by offering pigs a choice of isoenergetic diets differing in protein content (Kyriazakis, 1989 and Bradford and Gous, 1991a and b). It has been reported that individually housed young pigs (Kyriazakis et al, 1991) and growing-finishing pigs (Kyriazakis and Emmans, 1992) or group housed growing pigs (Bradford and Gous, 1991a, 1991b) have the ability to select a protein level to meet their requirements for protein when provided a choice of isoenergetic diets of high and low protein content. However, recent results (Owen et al., 1994; Nam and Aherne, 1994) reported that choice-fed pigs overconsume dietary protein by selecting more of the high protein diet as result of the in strong preference for a high protein diet. Contributing to this disagreement in results may be the range in the protein levels of the diets fed (Bradford and Gous, 1991a), and(or) differences in protein sources used (Kyriazakis and Emmans, 1992). As suggested by Emmans and Fisher (1986), a preference for the high protein diet may be due to differences in the palatability of diets offered. It is also possible that the feed intake of choice-fed pigs may be affected by the amino acid balance of the diets fed (Henry, 1985; ARC, 1981). However, little information exists regarding diet selection between a diet supplemented with amino acid(s) and unsupplemented diets.

Thus, the objectives of the present trial were 1) to compare choice feeding regimens with a conventional single feeding system, 2) to determine whether pigs have the ability to select a lysine intake and protein intake to meet their requirements, 3) to determine whether amino acid balance influences diet selection, and 4) whether the pattern of diet selection changes with increase in the pig's age or body weight.

B. EXPERIMENTAL PROCEDURES.

Animals and facility

Seventy-two gilts (Landrace x Yorkshire), of an average initial body weight of 24.6 kg, were allotted in groups of three to each of 24 (1.2 x 2.3 m) totally slatted floor pens. Room temperature was maintained at 20 to 22°C during the first 4 weeks, and 17 to 20°C thereafter. Equal numbers of pens were assigned to each of the four treatments. Dietary treatments consisted of control, **C**,

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[1] A version of this chapter has been submitted for publication. Nam, D. S. and Aherne, F. X. 1994. Anim. Feed Sci. Technol.

(conventional two phase feeding; 16-14% crude protein, CP), and three different choice feeding regimens: 1) protein choice, **PC**, 18 vs 10% CP, 2) lysine (Lys) choice, **LC**, 0.90 vs 0.53% Lys, 14% CP diets), 3) amino acid choice, **AC**, diets supplemented with a combination of Lys, methionine (Met), and threonine (Thr) based on an ideal protein ratio or an unsupplemented diet (Lys, 0.90 vs 0.53%; Met, 0.50 vs 0.45%; Thr, 0.59 vs 0.40%; in 14% CP diets). The 14% CP level in the **LC** and **AC** treatments was chosen as a mid point of the protein levels of the **PC** diets (10 and 18 CP). The two growth phases for **C** treatment were 25 to 50, and 50 to 70 kg live weight. To accustom pigs to the diets, choice-fed pigs were allowed access to each diet on alternate days for 7 days prior to the commencement of the experiment as suggested by Kyriazakis (1989). Within each pen, choice-fed pigs had access to two single-hole feeders and pigs assigned to the single feeding regimen had access to one two-hole feeder. The position of the feeders, within pens assigned to choice feeding, was not changed throughout the experiment, as it has been reported that feeder position does not affect diet selection by pigs (Kyriazakis, 1989). The position of the two feeders, however, was randomized across pens. Individual pig's weight gain and pen-based feed intake were recorded weekly.

Diets

All diets were based on wheat, barley and soybean meal, formulated to contain 13.7 MJ DE/kg and provided sufficient vitamins and minerals to meet the pig's requirement for growth (NRC, 1988). The composition of the experimental diets is presented in Table III.1. Feed and water were available at all times during the trial. The lower protein diet was formulated to be inadequate in CP to support potential growth when offered alone on an ad libitum basis (NRC 1988). The CP of the high protein diet was intended to be above the protein requirement of the pigs. The ratio of lysine to protein was fixed in both diets. Diets were assayed for CP (N x 6.25) by the Kjedahl method (AOAC, 1990). Separation and quantification of amino acids was accomplished with a Varian 5000 High Performance Liquid Chromatography and a Varian Fluorichrom detector (excitation 340 nm, emission 450 nm). Each sample (0.1 g) was hydrolyzed with 3 mL of 6N HCl for 24 hr at 110°C. Samples were mixed 1:1 with the fluoraldehyde reagent prior to injection, then 25 μL of mixed sample was injected onto a Supelcosil 3 micron LC-18 reverse phase column (4.6 x 150 mm; Supelco, Oakville, ON). The amino acid composition of the experimental diets with their amino acid ratio of ideal protein are presented in Table III.2.

Statistical Analysis

All data were analyzed by ANOVA using the GLM procedure appropriate for a randomized block design (SAS, 1985). One pig from the **LC** treatment was removed from the trial due to poor health. Means of each treatment were compared using the Student-Newman-Keuls test for each variable. When initial weight was noted to be significant ($P < 0.05$) in the model, initial body weight was used as a covariate for analysis of growth performance. Data for the pattern of diet selection in the choice-fed pigs were analyzed up to 7 wk because some pigs in each pen reached 70 kg body weight and remove from trial, resulting in disturbance of the social balance in the pen. The proportion of total intake accounted for by the high protein and amino acid(s) supplemented diets was compared for the different growth phases within each treatment. Each pen was considered as an experimental unit.

C. RESULTS

As presented in Table III.3, there were no significant differences in performance between control and PC pigs at any stage of growth. Growth rate and feed to gain ratio of C and PC pigs were superior ($P < 0.05$) to that of either LC or AC pigs from 25 to 50 kg, 50 to 70 kg and the overall period. There were no significant differences in feed intake for any of the treatments at any stage of growth. There was also no significant difference in performance between **LC** and **AC** pigs.

The proportion of the high protein diet selected by choice-fed pigs and the resulting dietary protein content in the diet consumed are presented in figures III.1a and III.b. Similar data for diet selection by LC and AC pigs is shown in Figures III.2a and III.2b, and III.3a and b, respectively. Choice-fed pigs (**PC**) showed a strong ($P < 0.01$) preference for the high protein diet at any weight interval. More than 89% of the in total feed intake was selected as the high protein diet. The pigs did not change their diet selection pattern to the low protein diet with an increase in body weight. The diet selection pattern was reflected in the average CP content (%) of the diets consumed which were 16.93, 17.03, and 16.98% from 25 to 50, 50 to 70 and 25 to 70 kg body weight (Figure III.1b). The protein content of the diets consumed by **PC** pigs was higher ($P < 0.01$) than that selected by the control pigs. Unlike **PC** pigs, **LC** pigs showed an almost equal preference (44.8% of total feed intake as high lysine diet) for the high and low lysine diets from 25 to 50 kg but reduced ($P < 0.05$) their consumption of the high lysine diet to 27.0% of total feed intake during the 50 to 70 kg period (Figure III.2a). For the overall period, the high lysine diet constituted 35.7% of total feed intake for the LC pigs. The lysine content of the diets selected by **LC** pigs in both growth phases was 0.68 and 0.61%, respectively, and lower ($P < 0.01$) than that consumed by the control pigs (Figure III.2b). The proportion of the amino acid supplemented diet selected by **AC** pigs decreased from 37.5 to 25.5% of total feed intake with an increase in body weight (Figure III.3a), but this decline was not significant. The overall proportion of the amino acid supplemented diet selected was 31.8% of total feed intake and there was a significant difference in the overall lysine content of diets consumed by C and AC pigs (0.72 vs 0.63%).

A comparison of the nutrient intakes and efficiency of nutrient utilization for weight gain are presented in Table III.4. The dietary protein intake of **PC** pigs was higher ($P < 0.05$) than that of

LC and **AC** pigs, but was similar to that of control pigs from 25 to 50 kg body weight. The PC pigs consumed ($P < 0.05$) more dietary protein than control and **LC** pigs, but not more than AC pigs during the 50 to 70 kg period. Over the entire experimental period, the **PC** pigs had higher ($P < 0.05$) protein consumption than pigs in the other treatments. Although the phase-fed pigs (C) required numerically less dietary protein per kg weight gain (protein intake to gain) than **PC** pigs at any weight, the ratio of protein intake to gain of all treatment groups was not affected by dietary treatment.

The dietary lysine intake showed a similar trend to that of protein intake; the PC pigs had a higher ($P < 0.05$) lysine intake than any other treatment group at any weight range. There was no significant difference in lysine intake among the other treatments (**C**, **LC**, and **AC**). Lysine intake to gain ratio was not different ($P > 0.05$) across treatments from 25 to 50 and 50 to 70 kg. Over the entire experiment, **LC** pigs had a more ($P < 0.05$) efficient utilization of lysine intake to gain than **PC** pigs, but it was not different ($P > 0.05$) from that of **LC** and **AC** pigs.

The pattern of diet selection by pigs for each week of the experiment for PC, LC, and AC treatments, together with their respective standard errors is presented in Table III.5. Data were analyzed up to 7 week of the trial because some pigs already attained 70 kg body weight at that time. Regression analysis was conducted to determine whether or not diet selection reflected the changing nutrient requirements of the pig throughout the trial. For the **PC** pigs, the change in the proportion (%) of high protein diet selected increased linearly but not significantly at a rate of 1.2% per week ($R^2 = 0.31$). Thus, there was no significant change in the pattern of diet selection with time for **PC** pigs but for **LC** and **AC** pigs there was linear decline ($P < 0.01$) in the nutrient density of the diet throughout the experiment (Table III.5). The corresponding coefficients for LC and AC treatments were -5.9 ($R^2 = 0.93$), and -3.3 ($R^2 = 0.91$) per week, respectively, indicating the decrease of the proportion in the supplemented diets selected with time.

D. DISCUSSION

The similar growth performance observed in this trial between control and PC pigs (Table III.3) is in agreement with the results of others (Bradford and Gous, 1991a; Nam and Aherne, 1994; Owen et al, 1994). The low protein content of the **LC** and **AC** diets may have contributed to the relatively poor performance of pigs fed these diets. The proportionally lower intake of the lysine supplemented and amino acid supplemented diet (Figure III.2a and III.3a) by LC and AC pigs also resulted in a decreased dietary protein and lysine intake of these pigs compared with control and **PC** pigs (Table III.4), which also contributed to the poorer performance of **LC** and **AC** pigs. This lack of a difference in performance between **LC** and **AC** pigs is in agreement with the results of Lopez et al (1994) who reported that feeding a diet formulated n the basis of ideal protein did not improve pig performance compared to diets formulated on a crude protein basis. Henry (1987) reported that choice-fed growing pigs allowed to select between diets deficient in lysine (0.60%) and containing excess lysine (1.21 or 1.40%) showed no significant difference in weight gain, lysine intake, and feed to gain ratio compared to pigs fed a single diet. Previous studies (Russell et al, 1983; Russell and Easter, 1986; Russell et al, 1987) have shown that supplementation of amino acids to low protein diets improved pig performance when a single diet was fed but when pigs were offered an amino acid(s)-supplemented and -unsupplemented diet (**LC** and **AC**), growth performance was not improved.

For the **PC** treatment in the current study, the high protein diet accounted for more than 80% of the total feed intake. This strong preference for a high protein diet was not observed in our previous study (Nam and Aherne, 1994) or in those of others (Owen et al, 1994; Bradford and Gous, 1991a; Kyriazakis. 1989). Bradford and Gous (1991a and b) and Kyriazakis (1989) reported that the proportion of the high protein diet selected by pigs given a choice of low and high protein diets declines as the pig matures, which also conflicts with the observations in this trial. Henry (1987) suggested that the selection of one diet over a~other at any given age depends on the proximity of the dietary protein level to that of the pig's protein requirement. The range in protein levels offered in the current experiment (18 vs 10%) was narrower than those used in previous studies (Nam and Aherne, 1994; Owen et al, 1994; Bradford and Gous, 1991b) and the high protein level was relatively close to the pigs requirement, which could explain why the consumption of the high protein diet was greater than observed in other studies.

In contrast to the pig's strong preference for the high protein diet, the **LC** and **AC** pigs consumed less of the diets supplemented with amino acid(s). The overall consumption of the amino acid(s) supplemented diet was 35.7 and 31.8% of total feed intake for **LC** and **AC** pigs, respectively. This avoidance of the amino acid(s) supplemented diet may be due to an amino acid imbalance of the diet (Henry, 1985). If animals are offered a choice of two diets, they will select a diet with a balanced pattern of amino acids in preference to one containing a disproportionately high amount of one or more indispensable amino acids (review of Harper and Peters, 1989). Lysine supplementation, to the 14% CP diet in this trial, reduced the ratio of all other amino acids relative to lysine and for most amino acids the resulting ratios were lower than those suggested by Wang and Fuller (1989) in Table III.2. If the change in the amino acid ratio of the lysine supplemented diet contributed to the reduced intake of the lysine supplemented diet, then the supplementation of lys, met, and thr which brought all amino acids except valine closer to an ideal amino acid ratio of pigs should have eliminated the problem (Table III.2). However, intake of this supplemented diet was still significantly reduced. This result indicated that the amino acid balance in the diet seems not to be main factor affecting diet selection of pigs.

A change in dietary electrolyte balance (dEB) in amino acids supplemented diets may also have contributed to a lower intake of these diets. Supplementation with lysine, in particular, lowered the dEB value of the **LC** and **AC** supplemented diets (Table III.1). The dietary electrolyte balance (dEB, mEq/kg) of the experimental diets, based on the $Na^+ + K^+ - Cl^-$, was within a range of 79 to 175 mEq/kg of diet and three of the diets had values below 100 mEq/kg (Table III.1). Patience et al (1987) reported that intake of diets with an dEB below 100 mEq/kg was reduced. Therefore, the acid-base status of these diets in this trial could have been a factor in the pattern of diet selection. Pigs given the choice of high or low protein diets avoided the low protein diet which had a dEB similar to that of the amino acid(s) supplemented diets (Table III.1). This observation further supports the hypothesis of an acid-base effect on diet selection.

Decreased consumption of the amino acid(s) supplemented diet over time reflected the declining requirement for amino acids as the pigs grew (Figure III.2a and III.3a, and Table III.5), even though the dietary lysine content of the diets selected was lower than that of the control. The **PC** pigs selected an approximately constant proportion (overall 89.8%) of the high protein diet in any period (Figure III.1a and Table III.5). Fairley et al (1993), using two diets differing in the level of one amino acid (digestible lysine or threonine), reported that few pigs selected a blend of diets which provided an appropriate amino acid concentration. These observations indicate that pigs do not have the ability to control their protein and lysine intake to meet their requirement. This observation is in contrast to that of Kyriazakis (1989) and Bradford and Gous (1991a, 1991b) who reported that the proportion of high protein intake and dietary protein content of diets selected decreased as the pig's body weight increased.

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Table III. 1. Composition of the experimental diets

Items	Conventional Two Phase		Choice Treatments					
			Protein		Lysine		Amino acids	
	Phase 1	Phase 2	High	Low	High	Low	+	-
Ingredients (g/kg)								
Wheat	330.3	245	385.3	139.9	689.7	685	700	685
Barley	450	580	367	771	205	200	190	200
Soybean meal (46%	154	100	188	-	54	67	54	67
Tallow	28	37	22	50	10	12	12	12
Limestone	11	11	11	11	11	11	11	11
Dicalcium	12	12	12	12	11	11	11	11
Salt	4	4	4	4	4	4	4	4
Vitamin-mineral	10	10	10	10	10	10	10	10
Lysine-HCl	0.7	1	0.7	2.1	5.3	-	5.3	-
Methionine	-	-	-	-	-	-	0.6	-
Threonine	-	-	-	-	-	-	2.1	-
Nutrients (As fed basis)								
DE[2], MJ/kg	13.70	13.70	13.70	13.70	13.70	13.70	13.70	13.70
dEB, mEq/kg[3]	158	132	175	79	90	127	89	127
Crude protein, %	15.95	14.16	17.7	10.2	14.1	14.0	14.3	14.09
Lysine, %	0.78	0.68	0.90	0.50	0.90	0.53	0.90	0.53
Methionine+cystine[2],	0.50	0.45	0.55	0.35	0.44	0.45	0.50	0.45
Threonine, %	0.47	0.41	0.54	0.27	0.38	0.40	0.59	0.40
Calcium[2], %	0.71	0.70	0.72	0.68	0.69	0.68	0.67	0.68
Phosphorus[2], %	0.62	0.61	0.64	0.57	0.60	0.58	0.58	0.58

[1] Vitamin mineral premix supplied the following per kg of diet: 5,000 IU vitamin A, 500 IU vitamin D, 40 mg vitamin E, 30 µg vitamin B_{12}, 12 mg riboflavin, 45 mg niacin, 25 mg pantothenic acid, 300 mg choline, 5 mg Ethoxyquin, 150 mg Fe, 20 mg Mn, 120 mg Zn, 20 mg I, 20 mg Cu, 0.3 mg Se.

[2] Calculated values.

[3] dEB:dietary electrolyte balance, calculated values based on the $Na^+ + K^+ - Cl^-$ content of ingredients as described by (Patience et al. 1987).

Table III. 2. Dietary crude protein and amino acid composition (%) of experimental diets (as-fed) and amino acid ratio in ideal protein

Amino acids	Control	Unsupplemented diet	Amino acid(s) supplemented diet		Ideal protein ratio[1]
			Lys	Lys + Met + Thr	
Crude protein	14.16	14.09	14.17	14.33	
Lysine	0.68	0.53	0.90	0.90	100
Methionine+cystine[2]	0.45(66)	0.45(85)	0.44(49)	0.50(56)	55
Threonine	0.41(60)	0.40(75)	0.38(42)	0.59(66)	65
Tryptophan[2]	0.18(26)	0.18(34)	0.18(20)	0.18(20)	18
Isoleucine	0.52(76)	0.51(96)	0.50(56)	0.50(56)	60
Leucine	0.93(137)	0.93(175)	0.92(102)	0.92(102)	100
Valine	0.55(81)	0.55(104)	0.54(60)	0.54(60)	70
Phenylalanine+tyrosine	0.95(140)	0.94(177)	0.93(103)	0.93(103)	100
Histidine	0.30(44)	0.31(58)	0.30(33)	0.30(33)	30

[1] Based on the ideal protein ratio suggested by ARC (1981), Wang and Fuller (1989), and Chung and Baker (1992).

[2] Calculated values.

Values in bracket represent the ratio relative to lysine.

Table III. 3. Performance of pigs fed control or a pair of diets differing in protein, lysine, or amino acid content[1]

Body weight, kg	Control	Choice feeding			SEM[2]
		Protein	Lysine	Amino acid	
		18 vs 10	0.90 cs 0.53	+ vs -	
25-50					
Weight gain, g/d	761[a]	771[a]	670[b]	632[b]	19.3
Feed intake, kg/d	1.80	1.90	1.84	1.84	0.08
Feed/gain, kg/kg	2.36[a]	2.53[a]	2.78[b]	2.97[b]	0.11
50-70					
Weight gain, g/d	883[a]	960[a]	732[b]	770[b]	29.7
Feed intake, kg/d	2.56	2.61	2.53	2.75	0.15
Feed/gain, kg/kg	2.85[a]	2.70[a]	3.54[b]	3.57[b]	0.19
25-70					
Weight gain, g/d	815[a]	841[a]	703[b]	688[b]	19.4
Feed intake, kg/d	2.13	2.22	2.15	2.25	0.08
Feed/gain, kg/kg	2.60[a]	2.66[a]	3.06[b]	3.27[b]	0.13

[1] Data are means of six replicates of three pigs each. Average initial body weight was 24.6 kg.

[2] Standard error of the mean, n = 6.

[a, b, c] Means within a row with a different superscript letters differ, $P < 0.05$.

Table III. 4. Intake of selected nutrients and efficiency of weight gain of single- and choice-fed pigs[1]

		Choice feeding[2]			
Body weight, kg	Control	Protein	Lysine	Amino acid	SEM[2]
		18 vs 10	0.90 vs 0.53	+ vs -	
25-50					
Protein intake, g/d	287^{ab}	330^{a}	261^{b}	265^{b}	15
Protein intake to gain, g/kg	377	428	393	422	17
Lysine intake, g/d	14^{b}	16.7^{a}	12.5^{b}	12.2^{b}	0.76
Lysine intake to gain, g/kg	18.4	21.7	18.9	19.3	0.9
50-70					
Protein intake, g/d	357^{b}	448^{a}	359^{b}	387^{ab}	22
Protein intake to gain, g/kg	404	467	499	505	29
Lysine intake, g/d	17.2^{b}	22.7^{a}	15.5^{b}	16.5^{b}	1.1
Lysine intake to gain, g/kg	19.4	23.3	21.5	21.4	1.4
25-70					
Protein intake, g/d	316^{b}	379^{a}	302^{b}	319^{b}	17
Protein intake to gain, g/kg	388	452	432	464	20
Lysine intake, g/d	15.3^{b}	19.1^{a}	13.8^{b}	14.1^{b}	0.83
Lysine intake to gain, g/kg	18.8^{a}	22.9^{b}	19.7^{ab}	20.5^{ab}	1.0

[1] Data are means of six replicates of three pigs each. Average initial body weight was 24.6 kg.

[2] Standard error of the mean, n = 6.

$^{a, b, c}$Means within a row with a different superscript letters differ, $P < 0.05$.

Table III. 5. The proportion of the high protein, lysine supplemented,and amino acids supplemented diet selected by choice-fed pigs[1].

	The proportion of the selected diet (% of total feed intake)					
Week	High protein[2]	SE	Lysine supplemented[3]	SE	Amino acids supplemented[4]	SE
1	80.2	2.2	58.7	2.4	48.1	3.3
2	90.0	1.2	53.3	2.6	42.5	5.4
3	88.4	1.4	50.8	3.7	37.2	4.3
4	91.7	0.9	42.6	4.1	33.9	5.0
5	93.6	1.6	32.6	4.9	36.7	4.8
6	92.6	1.7	24.9	3.3	28.6	4.5
7	87.5	2.7	29.0	3.8	26.9	4.5

[1] Y=aX = b (Y: the proportion (%) of the selected diet; X:week)

[2] a = 1.2 (R^2 = 0.31). [3] a = -5.9 (R^2 = 0.93). [4] a = -3.3 (R^2 = 0.91)

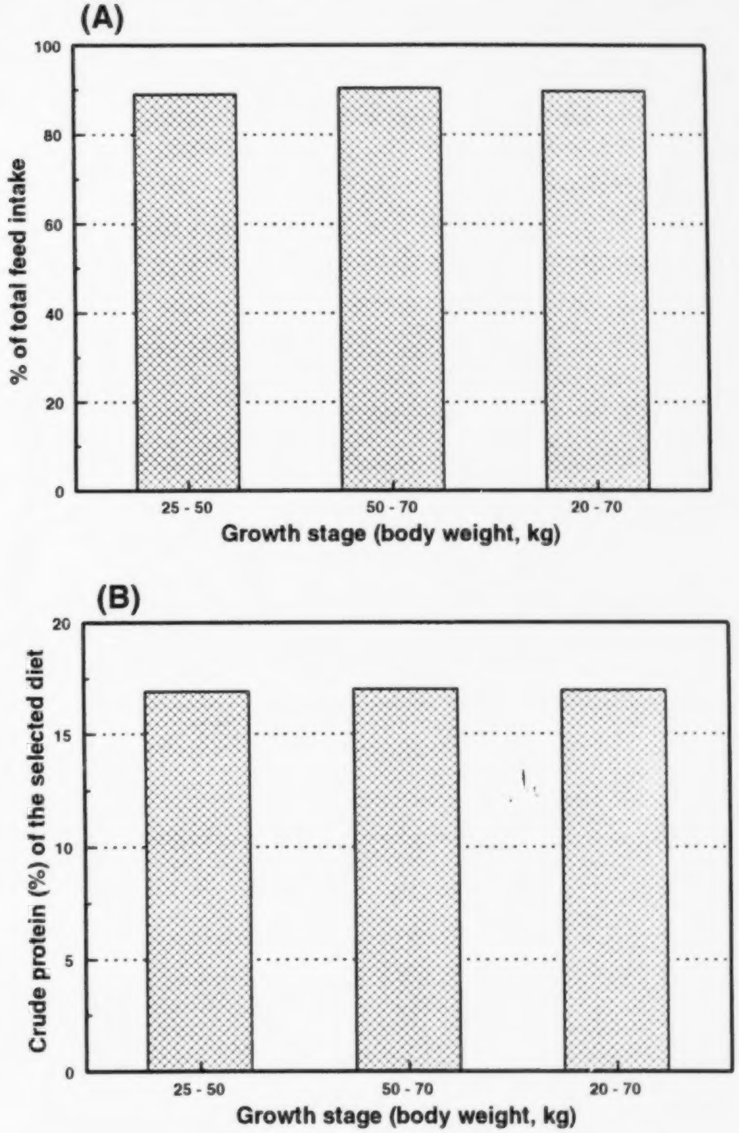

Figure III. 1. The diet selection pattern by PC pigs (A: the proportion of the high protein diet selected (% of total feed intake); B: crude protein content (%) of the diet consumed).

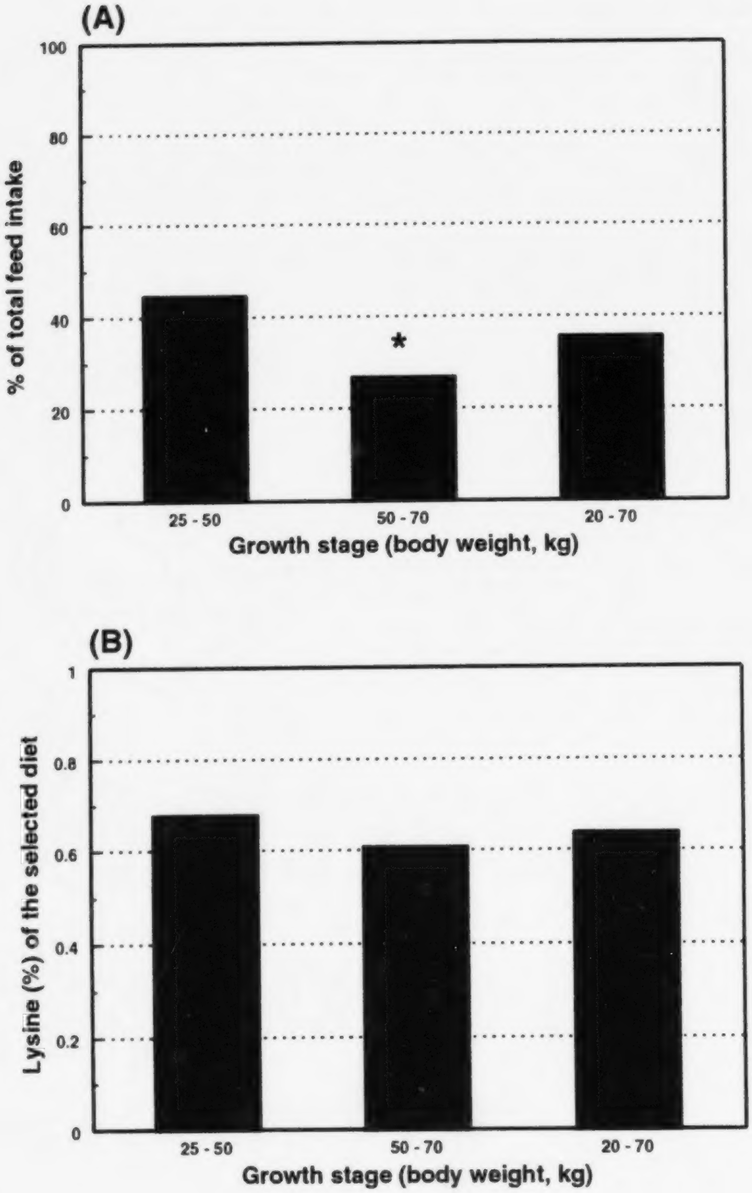

Figure III. 2. The diet selection pattern by LC pigs (A: the proportion of the lysine supplemented diet selected (% of total feed intake); B: lysine content (%) of the diet consumed), *:$P < 0.05$.

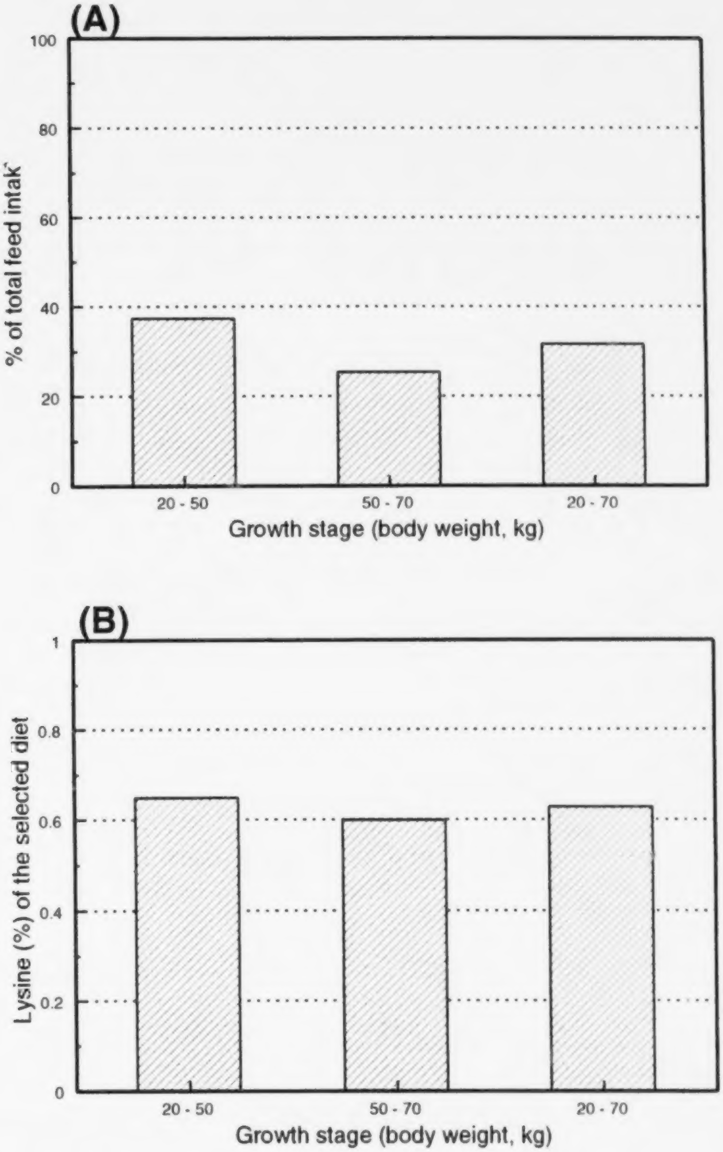

Figure III. 3. The diet selection pattern by AC pigs (A: the proportion of the amino acids supplemented diet selected (% of total feed intake); B: lysine content (%) of the diet consumed).

IV. THE SELECTION OF PROTEIN INTAKE BY PIGS TREATED WITH PORCINE SOMATOTROPIN (ST)[1]

A.INTRODUCTION

Conventional feeding systems, which provide a single diet for a period of time, do not allow for differences between animals in genetic merit. Hence, pigs of a lower than average growth rate consume more protein than they can use, whereas pigs of greater than average growth rate may fail to achieve maximum growth rate due to limited protein intake, or may deposit more fat as a consequence of overeating to meet their protein/amino acid requirement. If we feed each pig to express its growth potential, considerable economic benefits may accrue compared with a conventional system that offers pigs a single diet.

It has been demonstrated in a series of recent experiments (Kyriazakis, 1989; Kyriazakis et al., 1990; Kyriazakis and Emmans, 1991; Bradford and Gous, 1991a and b) that pigs can distinguish between pairs of diets of different protein concentration and they can adjust their protein intake to reflect their individual requirement. This occurs only if one diet has a protein level above the pigs' requirement and the other below the requirement and both diets are isoenergetic.

Growing-finishing pigs given porcine somatotropin (ST) grow faster and deposited more lean (Chung et al., 1985; Goodband et al., 1993). They do this by partitioning more nutrients to increased protein deposition and less nutrients to deposition of fat (Chung et al., 1985; Campbell et al.,; 1990 Boyd and Krick, 1991). To support this increase in growth rate and protein deposition, pigs may require an increase in dietary energy, and amino acids (Boyd and Krick, 1991).

The objective of the present study was to test the hypothesis that pigs, when offered a choice of diets differing in protein content, have the ability to select more protein to meet their requirement for increased lean growth induced by ST treatment.

B. EXPERIMENTAL PROCEDURES.

Animals and Diets

Seventy-two gilts (PIC Camborough x Canabrid; PIC Acme, Canada)), of an average initial body weight of 20 kg, were allotted in groups of 18 to each of four pens with half-slatted floors (4.4 m x 4.8 m) containing two electronic feeders (Hunday Electronics, Newcastle, U.K.). The electronic feeders (Feed Intake Recording Equipment, FIRE) allowed access to only one pig at a time. When a pig visited the feeder, it was identified by its ear tag transponder and its entry and exit times and the amount of feed consumed (kg) were monitored and transferred to a personal computer. Records were generated continuously for individual pigs. At the beginning of the trial, two pigs close to the average BW per pen were killed for carcass analysis. The remaining 64 pigs were grouped (16 per pen) and assigned to the experimental treatments from 33 to 100kg BW. All pigs were offered a 18% CP diet from 23 to 33 kg BW. The pigs were trained to use the electronic feeders by initially putting a small amount of feed in the front of the feeders. Choice-fed pigs had access to a 10% (low) and 24% (high) CP diet throughout the grower and finisher periods. For pigs assigned to the single diet, the two feeders in each pen contained a 16% protein diet during the grower period (33 to 65 kg) and 14% protein from 65 to 100kg BW. The choice-fed pigs were allowed access to each diet on alternate days for 10 d before the commencement of the experiment. All diets contained 10% commercial sugar to mask possible differences in palatability (Table IV.1). All diets were based on barley and soybean meal, formulated to contain 13.7 MJ of DE/kg and provided vitamins and minerals at or above the levels suggested to meet the pig's requirement for growth (NRC, 1988). The diets were fed as pellets and water was provided ad libitum through nipple waterers. Diets were assayed for CP (N x 6.25) by the Kjedahl method (AOAC, 1990). Separation and quantification of amino acids was accomplished with a Varian 5000 High Performance Liquid Chromatography and a Varian Fluorichrom detector (excitation 340 nm, emission 450 nm). Each sample (0.1 g) was hydrolyzed with 3 mL of 6N HCl for 24 hr at 110°C. Samples were mixed 1:1 with the fluoraldehyde reagent prior to injection, then 25 µL of mixed sample was injected onto a Supelcosil 3 micron LC-18 reverse phase column (4.6 x 150 mm; Supelco, Oakville, ON).

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[1] A version of this chapter has been accepted for publication. Nam, D. S., Aherne, F. X, He, P, Weingardt and Schaefer, A. L. 1994. J. Anim. Sci.

To induce differences in lean growth, from 33 kg BW, half the pigs in each pen received a daily injection of 100 µg/kg BW of porcine somatotropin (ST: Pitman-Moore, Terre Haute, IN) in sterile buffer (0.03 M $NaHCO_3$, 0.15 M NaCl, pH 9.5). This dose of ST was selected because it resulted in maximal acheviable response in previous studies (Boyd et al. 1986; McLaren et al. 1990)y optimized The other pigs were injected daily with a similar volume of buffer that acted as a placebo. Daily intramuscular injections were administered at alternate sides of the neck, near the base of the ears, between 0800 and 0900 h. The amount of ST or placebo administered was adjusted weekly, according to the individual pig weights. At 65 kg BW, three ST-treated pigs per pen were withdrawn from ST treatment, but remained on test, and were monitored for subsequent performance.

Blood Collection and Analysis

At the beginning of the trial, blood was collected 3 h after ST injection. At average weights of 65 and 100kg, blood samples were collected at 3 h after ST or saline injection. Blood samples were (15 mL) taken from each pig by anterior vena cava puncture using a 14-gauge needle and were stored in evacuated heparinized tubes. Blood was centrifuged at 3000 x g for 15 min at 4°C.

Plasma fractions were stored at -20°C until analyzed for plasma urea nitrogen (PUN), growth hormone (GH), Insulin growth factor-I (IGF-I), insulin, and glycerol. Plasma samples were assayed for GH using the double-antibody RIA procedure of Marple and Aberle (1972) with modifications as described by Beltranena et al (1993). Plasma insulin concentrations were determined using a homologous double-antibody RIA described by de Boer and Kennelly (1989). Concentrations of IGF-I were assayed using the homologous double-antibody RIA described by Glimm et al. (1988). Concentration of PUN was determined by enzymatic colorimetric methods (Sigma Chemical, St. Louis, MO). Glycerol levels in plasma were analyzed by capillary gas chromatography (Fenton and Aherne, 1987).

Carcass Data Collection

In addition to the eight pigs dissected at the beginning of the trial, when pen average BW was close to 65 kg, four pigs closest to 65 kg BW were selected for slaughter. The remaining 12 pigs per pen were slaughtered when they reached 100 kg BW. All pigs slaughtered were dissected into fat, lean, and bone components following the procedures of Martin et al. (1981). All pigs were stunned by electrical shock (400 volt for 2 or 3 s), bled, scalded, and dressed according to normal commercial procedures. The carcasses were chilled for 24 h at 1°C and the right side of each carcass was dissected. Samples of lean were collected for analysis of CP, DM (AOAC, 1990), fat (Folch et al., 1957), and fatty acids. Fatty acid composition was determined as described by Morrison and Smith (1964). The fatty acid methyl esters were separated and quantified using gas chromatography apparatus (Varian 3400, Varian Associates Inc., Walnut Creek, CA 94598). The identification of fatty acid peaks was carried out by running known fatty acid standards purchased from Sigma Chemical Co., St. Louis, MO 63178), along with the methylated fatty acid samples. Hennessy Grade Probe (Hennessy and Chong, Auckland, New Zealand) measurements were made between the 9th and 10th ribs, 70 mm from carcass mid-line for fat and muscle depth. Lean yield content was estimated using the following equation (Agriculture Canada, 1986); Lean yield (%) = 54.31 - 0.36 (fat depth, mm) + 0.06 (muscle depth, mm). Maximum fat thickness was also recorded on the mid-line of the carcass at the 10th rib, loin and lumbar (over gluteus medius) positions.

Statistical Analysis

One ST-treated pig fed the 16% CP diet was removed from the analysis as an outlier due to extremely low appetite with poor health during the first 2 wk. All data were analyzed by the GLM procedures of SAS (1985). Results were presented as least square means for the feeding x ST effects in each growth stage. Preliminary analysis was done to check any effect of pen on each variable. After confirming that there was no effect of pen, all data were analyzed using a two-way factorial analysis with fixed factors as feeding system and ST treatment. Initial BW and carcass weight were used as covariates for analysis of growth performance and carcass characteristics, respectively. Data for the pattern of diet selection in the choice-fed pigs were analyzed up to 9 wk because some pigs in each pen were removed for slaughter, resulting in disturbance of the social balance in the pen. Because pigs were nested within treatment x feeding system, individual pigs were used as the experimental units in the ANOVA and this represented a replication number of n = 16 for the growing period and 12 or 6 for the finishing and the entire experimental period.

C. RESULTS

Choice-fed pigs consumed less ($P = 0.018$) feed and grew more slowly ($P = 0.05$) without differing in feed efficiency during the grower period (33 to 65 kg) than pigs assigned to the single-feeding system (Table IV.2). Treatment with ST during the grower period did not affect weight gain but improved ($P < 0.05$) feed: as a result of the reduced ($P < 0.05$) feed intake. In the finishing period, choice-fed pigs grew faster($P = 0.07$), had better feed efficiency ($P = 0.001$), and consumed less feed ($P = 0.02$) than pigs assigned to the 14% CP diet. Treatment with ST in the finisher period decreased feed intake ($P = 0.04$), increased the feed:gain ratio ($P = 0.001$) but had no effect on weight gain. Even though choice-fed pigs treated with ST gained more than 1.0 kg/d, there was no effect of ST injection on growth rate, regardless of feeding system ($P = 0.35$). There was, however, a significant interactive effect of feeding system and ST injection on feed:gain in the finisher and overall period, choice-fed pigs treated with ST had increased weight gain and reduced feed intake. Pigs did not maintain their performance after withdrawal of ST at 65 kg in the finishing period, but reverted to a performance level similar to that of the control pigs. Over the whole period (33 to 100kg), injection of ST decreased ($P = 0.006$) feed intake and increased ($P = 0.001$) feed:gain with no significant effect on weight gain.

Pattern of diet selection by choice-fed pigs was not affected by length of experiment. As seen in Table IV.3, the proportion of the high-protein diet consumed did not decrease as the pig's body weight increased. The proportion of high protein diet selected did not differ significantly between treatments, although pigs treated with ST selected a slightly higher proportion of the high-protein diet than untreated pigs. As a result of the lower feed intake in ST treated pigs, the overall diet consumed by ST-treated pigs was higher ($P < 0.05$) in CP than that consumed by non-treated pigs.

There was no effect of ST treatment on the proportional intake of the high-protein diet compared with control pigs or those withdrawn from ST (Table IV.4). During the grower period (33 to 65 kg), injection of ST did not affect protein intake and resulted in a decrease ($P = 0.03$) in the required amount of protein per unit of weight gain. Choice-fed pigs consumed less ($P = 0.001$) protein and had a decreased ($P = 0.001$) ratio of protein intake:weight gain. In the finishing period, pigs treated with ST required less ($P = 0.03$) dietary protein for weight gain than untreated pigs. Choice-fed pigs utilized protein more efficiently for weight gain than single-fed pigs, with no difference in protein intake. Choice-fed pigs treated with ST required the least amount of protein per unit of weight gain. For the overall period (33 to 100kg), pigs treated with ST required less protein and feed per unit gain of weight than the control pigs or those withdrawn from treatment. Choice-fed pigs showed more efficient utilization of feed and dietary protein for weight gain, lean gain and protein deposited than single-fed pigs.

Injection of ST increased the amount of lean ($P = 0.001$) and bone ($P = 0.01$) and decreased ($P = 0.001$) the amount of fat in the carcass, irrespective of feeding system (Table IV.5). The decrease in fat was more pronounced than the increase in lean. There was no difference between pigs in the control group and those withdrawn from ST in the amount of dissected tissues. Choice-fed pigs had ($P = 0.02$) less intermuscular fat than single-fed pigs. There were no differences in amount of dissected tissues between choice and single feeding. Carcass weight was decreased ($P = 0.04$) by injection of ST (Table IV.5). Treatment with ST decreased ($P = 0.001$) dressing percentage and increased ($P = 0.01$) carcass grade index. Fat thickness measured by ruler at three points, the loin, rib, and lumber, was decreased ($P < 0.05$) by injection of ST. Measurements between 9th and 10th ribs, 70 mm from the carcass mid-line, when measured by the Hennessy Grading Probe, showed that pigs treated with ST had 40% less fat depth (10.7 to 11.5 mm) than pigs injected with saline or withdrawn from ST (16.6 to 17.8 mm). However, lean depth measured by the Hennessy Grading Probe was not affected by ST injection ($P = 0.11$). Predicted lean content calculated by the probe regression equation (from fat and lean depth) was increased ($P < 0.001$) by approximately 5% by ST injection compared with control and withdrawal from ST. Among the carcass measurements, only fat thickness was significantly reduced in choice-fed pigs compared with single-fed pigs. There was no significant interaction between ST treatment and feeding system for any measured carcass trait.

Injection with ST increased ($P = 0.001$) protein content and decreased ($P < 0.001$) the DM and fat content of the pig's lean tissue (Table IV.6). Injection of ST decreased ($P < 0.001$) the saturated fatty acids levels (SFA) and increased ($P < 0.001$) the unsaturated fatty acids (UFA) in the pig's lean tissue. The ratio of UFA:SFA was increased ($P = 0.001$) by injection of ST. Choice feeding resulted in an increase ($P = 0.004$) in SFA and a decrease ($P =0. 004$) in the ratio of UFA:SFA.

Deposition rate of carcass dissected tissues are presented in Table IV.7. During the grower period, 30 to 34% of the decrease ($P = 0.01$) in fat deposition rate and 8 to 10% of the increase ($P = 0.08$) in protein deposition rate were attributed to ST treatment. In the finisher period injection of ST increased ($P = 0.005$) the lean deposition rate in single- and choice-fed pigs (429.9 and 520.3 g/d), respectively. Bone deposition rate ($P = 0.03$) and protein deposition rate ($P = 0.001$)

was also increased by injection of ST (92.5 to 94.6 g/d and 81.9 to 105.5 g/d, respectively). Withdrawal of ST decreased lean, bone and protein deposition and increased fat deposition rate compared with pigs in the control group. For the overall period, injection of ST decreased ($P = 0.001$) fat deposition by 24 to 28% and increased ($P = 0.001$) lean and protein deposition rates by 18 to 27% and 25 to 35%, respectively. Deposition rate of carcass dissected tissues was not influenced by choice feeding. There was no interactive effect of ST treatment and feeding system on deposition rate of lean, bone, fat and protein.

Blood metabolite concentrations are shown in Table IV.8 and are in agreement with the results of others (Caperna et al., 1990; Dunshea et al., 1992; Goodband et al., 1993).

D. DISCUSSION

One of the objectives in the present study was to test the hypothesis that pigs given a choice of diets differing in protein content would select a combination which matches their protein requirements. We tested this hypothesis in two ways; 1) by observing how pigs change their diet selection pattern as they get heavier and older. Our expectation was that pigs would select less of the high protein and consume more of the low protein diet, and 2) by altering the lean growth potential by treating with ST, our expectation was that increased lean growth rate induced by injection of ST would encourage pigs to eat more of the high-protein and less of the low-protein diet at any particular body weight.

The proportion of the high-protein diet selected by choice-fed pigs did not change with increase in body weight or age of pigs even for pigs treated with ST (Table IV.4). In contrast to our expectation, pigs showed a nonsignificant preference for the high-protein diet as they grew. The enhanced lean growth induced by ST treatment resulted in these pigs selecting slightly more of the high protein diet than did non treated pigs, but this difference was not significant.

Although ST treatment did not increase weight gain compared with untreated pigs, it did increase the deposition rate of lean tissue and protein. The observation that ST injection did not affect weight gain of pigs in this study (Table IV.2) is in contrast to the results of some researchers (Chung et al., 1985; Etherton et al., 1987; Campbell et al., 1989) but is in agreement with others (Kraft et al., 1986; Azain et al., 1992). One reason for the lack of response may be that the intake of lysine was insufficient for the expression of the ST effect (Goodband et al., 1990, 1993). Goodband et al., (1993) suggested that the response of finishing pigs to ST is dependent on the dietary lysine level provided. Approximately 27 to 32 or 36 g/d of lysine are required for expression of maximum weight gain in pigs injected with 4 or 8 mg/d of ST, respectively (Goodband et al., 1993). Pigs in this trial were injected with 6 mg/d of ST and would need, according to Goodband et al (1993), to have consumed between 32 and 36 g/d of lysine to elicit the maximum ST effect. However, lysine intake in this trial was about 20 g/d, which would be insufficient for full expression of the ST effect. There are a number of reasons why the lysine intake was lower than expected. One such reason could have been the reduced feed intake that may have resulted from a reduced insulin tolerance leading to hyperglycaemia, increased maintenance requirement due to increased protein accretion and increased heat production, because of increased metabolic activity and protein turnover. The reduced feed intake and improved feed efficiency for ST treated pigs are typical of results seen by others (Chung et al., 1985; Campbell et al., 1989). The increased weight gain of choice-fed pigs in the finisher period may have been a compensatory response to the reduced growth rate observed in the grower period. The effect of withdrawal of ST injection on growth performance was similar to that reported by Smith and Kasson (1989). However, Campbell et al., (1989) demonstrated that the performance of pigs injected with ST from 30 to 60 kg was superior to that of non-treated pigs, but less than that of pigs injected continuously with ST.

The proportion of high-protein diet consumed by choice-fed pigs in this study (Table IV.4) did not change with an increase in body weight. No significant difference in the proportion of high-protein diet consumed was found between the grower and finisher period. Others (Kyriazakis et al., 1990; Kyriazakis and Emmans, 1991) have suggested that pigs, individually housed, have the ability to select a protein intake to meet their protein requirement when offered a choice of diets differing in protein content. In the current experiment, the distance (3.0 m) between the two feeders within pens and group size (16 pigs/pen for grower and 12 pigs/pen for the finisher period) may have influenced the selection of diet. Values for SEM in Table IV.3 suggest that there was a large variation in individual pig's diet selection when housed in groups. Monopolization of feeders by dominant pigs, when group-housed, may prevent other pigs from consuming the desired protein intake. Diet composition may also influence diet selection of pigs. In this trial, soybean meal was used as the source of protein and 10% commercial sugar was added to try to mask possible differences in palatability of the diets, whereas, fish meal was used as the protein source in the high-protein diet in other trials (Kyriazakis et al., 1990; Bradford and Gous., 1991b; Kyriazakis and Emmans, 1991). Reduced protein intake in choice-fed pigs in the grower and overall period as compared with pigs fed a single diet was opposite to the results reported by Bradford and Gous (1991b). The percentage of dietary protein consumed for the overall period in the single-feeding system was 15.2, 15.8, and 15.7% for non-treated, ST treated, ST withdrawn pigs, respectively. In choice-fed pigs, the percentage of dietary protein consumed was 14.7, 15.7, and 15.0% for non-treated, ST treated, and ST withdrawn pigs, respectively, for the overall period. Because of the reduced feed intake, pigs treated with ST showed an improved efficiency for conversion of dietary protein to weight and lean gain compared with control pigs.

In this trial the effects of ST on carcass quality (Table IV.5) were similar to those reported earlier (Campbell et al., 1989; Lefaucheur et al., 1992; McNamara et al., 1991; Goodband et al., 1993). Decreased carcass weight and dressing percentage in pigs treated with ST resulted from the increased organ weight and increased metabolic activity associated with greater protein deposition. The decreased fat thickness in choice-fed pigs in this trial was similar to the finding of Bradford and Gous (1991a) who reported that choice-fed pigs were generally leaner than phase-fed pigs.

The increased protein content and decreased DM and fat content of lean tissues from pigs treated with ST (Table IV.6) are in agreement with previous studies (Campbell et al., 1989; Lefaucheur et al., 1992; Noblet et al., 1992). Similarly, the elevated UFA due to ST treatment and decreased fat content have also been reported (Ender et al., 1989; Prusa et al., 1989). In contrast, Clark et al. (1992) reported that ST treatment had no effect on the lipid profile of the longissimus muscle. It is not clear why choice feeding resulted in modification of SFA and UFA in the lean tissue of pigs, but decreased protein intake (Table IV.4) may be one possible reason for the change in lipid profile.

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Table IV. 1. Ingredients and chemical composition of the experimental diets, as-fed basis

Item	Single feeding		Choice feeding	
	Grower	Finisher	High protein	Low protein
Ingredients, g/kg				
Barley	630	686	400	791
Soybean meal (48% CP)	210	152	440	35
Sugar	100	100	100	100
Tallow	25	27	15	38
Limestone	10	9	12	9
Dicalcium-phosphate	11	10	19	11
Salt	4	4	4	4
Vitamin-min Premix[1]	10	10	10	10
Lysine-HCl	-	2	-	2
Nutrients (as fed basis)				
DE[2], MJ/kg	13.71	13.69	13.72	13.69
Protein, %	16.27	13.89	24.38	9.97
Lysine, %	0.95	0.85	1.47	0.61
Calcium[2], %	0.66	0.59	0.93	0.59
Phosphorus[2], %	0.59	0.55	0.83	0.53

[1] Vitamin mineral premix supplied the following per kg of diet: 5,000 IU vitamin A, 500 IU vitamin D, 40 mg vitamin E, 30 μg vitamin B_{12}, 12 mg riboflavin, 45 mg niacin, 25 mg pantothenic acid, 300 mg choline, 5 mg Ethoxyquin, 150 mg Fe, 20 mg Mn, 120 mg Zn, 20 mg I, 20 mg Cu, 0.3 mg Se.

[2] Calculated value

Table IV. 2. Growth performance of pigs administered ST or a placebo under choice and single feeding systems[ab]

Item	Single feeding			Choice feeding			SEM	Statistical significance[c]
	Control	ST	Withdrawal	Control	ST	Withdrawal		
Grower (33-65 kg)								
No. pigs	15	16		16	16			
Weight gain, g/d	887	872		822	826		29	F^{*}
Feed intake, kg/d	2.24	2.05		2.09	1.89		0.06	F^{*} T^{**}
Feed/Gain	2.51	2.34		2.53	2.29		0.076	T^{**}
Finisher (65-100kg)								
No. of pigs	11	6	6	12	6	6		
Weight gain, g/d	986	921	867	972	1024	976	51	F^{+}
Feed intake, kg/d	2.73	2.48	2.73	2.62	2.18	2.65	0.11	F^{*} T^{**}
Feed/Gain	3.12	2.72	3.13	2.68	2.11	2.64	0.139	F^{**} T^{**} I^{**}
Whole period (33-100kg)								
No. of pigs	11	6	6	12	6	6		
Weight gain, g/d	940	888	883	902	945	866	31	
Feed intake, kg/d	2.50	2.25	2.45	2.37	2.06	2.24	0.03	F^{**} T^{**}
Feed/Gain	2.66	2.59	2.78	2.62	2.16	2.58	0.078	F^{**} T^{**} I^{**}

[a] Data presented as least square means with initial body weight used as covariate.

[b] Daily i.m injection of 100 µg/kg BW of porcine somatotropin were administered at alternate sides of neck, near the base of ears.

[c] Statistical significance of feeding system (F), ST treatment (T) or the interaction (I = FxT) indicated by $^{+}$(P < 0.10), *(P < 0.05), and **(P < 0.01). Other effects were not significant (P > 0.10).

Table IV. 3. Proportion of high-protein diet selected and protein content (%) of the diets chosen each week by choice-fed pigs

Week	Proportion of high-protein diet selected, %			Protein content of overall diet consumed, %		
	Control	ST	SEM	Control	ST	SEM
1	33.8	36.3	6.24	14.66	15.04	0.918
2	35.6	41.2	4.90	14.93	15.75	0.717
3	33.7	42.0	4.78	14.64	15.88	0.703
4	26.7^a	41.4^b	4.59	13.63^c	15.78^d	0.676
5	31.5	35.7	5.09	14.33	14.94	0.748
6	34.7^a	52.4^b	4.39	14.78^c	17.41^d	0.644
7	30.3	30.9	4.85	14.13	14.23	0.709
8	31.2	23.9	4.63	14.27	13.21	0.678
9	37.8	45.1	7.55	15.24	16.32	1.113
Mean	32.8	38.6	5.88	14.53	15.31	0.91

^{abcd}Means within a row no common superscript letters differ. ($P < 0.05$).

Control:injected with buffer as a placebo; ST:received a daily injection of 100 μg/kg BW of porcine somatotropin

Table IV. 4. Proportion of high-protein diet consumed, total protein intake and efficiency of protein and feed for lean and body weight gain in pigs administered ST or placebo under single and choice feeding systems

	Single feeding			Choice feeding				Statistical
Item	Control	ST	Withdrawal	Control	ST	Withdrawal	SEM	significance[a]
Grower period (33-65 kg BW)								
No. of pigs	15	16		16	16			
Proportion of HP, %[b]				32.3	39.4		3.86	
Daily PI, g/d[c]	367.3	339.5		299.5	294.2		14.11	F^{**}
PI/Gain, g/kg BW	409.4	383.7		370.1	356.6		4.70	F^{**} T^{*}
Finisher period (65-100 kg BW)								
No. of pigs	11	6	6	12	6	6		
Proportion of HP, %				35.4	41.6	34.6	5.05	
Daily PI, (/d	390.9	370.2	390.1	399.2	346.8	385.6	29.46	
PI/Gain, g/kg BW	391.7	397.0	446.5	406.7	338.3	406.9	7.90	F^{+} T^{*} I^{+}
Whole period (33-100 kg BW)								
No. of pigs	11	6	6	12	6	6		
Proportion of HP, %				33.9	40.6	35.3	2.17	
Daily PI, g/d	380.9	355.8	369.8	346.8	322.7	335.8	26.13	F^{*}
PI/Gain, g/kg BW	400.6	388.7	418.6	390.2	342.5	392.0	5.72	F^{**} T^{+}
Feed/Lean, g/g	6.72	6.15	7.13	6.95	4.96	6.50	0.14	F^{*} T^{**} I^{*}
Feed/PD, g/g[d]	35.24	30.03	37.07	36.21	24.10	34.28	0.82	F^{*} T^{**} I^{*}
PI/Lean, g/g	1.01	0.92	1.07	1.02	0.79	0.98	0.02	F^{*} T^{**}
PI/PD, g/g	5.30	4.51	5.57	5.33	3.82	5.14	0.12	F^{+} F^{**}

[a] Statistical significance of feeding system (F), ST treatment (T) or the interaction (I = FxT) indicated by $^{+}$(P < 0.10), *(P < 0.05), and **(P < 0.01). Other effects were not significant (P > 0.10).

[b] HP = High-protein. [c] PI = Protein intake. [d] PD = Protein deposition.

Table IV. 5. Carcass measurements of pigs administered ST or a placebo under single and choice feeding systems[a]

Item	Single feeding			Choice feeding			SEM	Statistical Significance[b]
	Control	ST	Withdrawal	Control	ST	Withdrawal		
No. of pigs	11	6	6	12	6	6		
Kill wt, kg	101.9	101.0	101.2	100.3	102.6	100.5	0.46	
Cold carcass wt, kg	72.9	69.2	71.8	71.6	69.9	71.5	0.38	T^{*}
Dress percentage	80.2	77.3	79.8	79.8	76.7	79.6	0.16	T^{**}
Grade index	107.8	110.7	108.8	109.0	112.3	109.5	0.48	T^{**}
Fat thickness, mm								
Loin	20.83	12.83	19.60	18.33	9.50	17.83	0.70	F^{**} T^{**}
Lumbar	21.67	13.00	19.60	18.92	10.00	18.67	0.71	F^{*} T^{**}
Rib	27.17	16.33	25.60	24.75	13.33	24.67	0.90	F^{+} T^{**}
Hennessy Probe								
Fat, mm	17.8	11.5	17.7	17.3	10.7	16.6	0.52	T^{**}
Lean, mm	48.1	41.3	43.4	45.5	45.6	43.1	0.83	
Lean yield, %	50.74	52.58	50.48	50.78	53.12	50.88	0.18	T^{**}
Lean, kg	19.16	20.49	19.07	18.85	21.24	19.33	0.19	T^{**}
Bone, kg	4.30	4.75	4.23	4.36	4.60	4.51	0.05	T^{*}
Subcutaneous fat, kg	8.00	6.61	8.04	8.36	6.07	7.78	0.19	T^{**}
Intermuscular fat, kg	1.57	1.08	1.47	1.39	0.98	1.35	0.04	F^{*} T^{**}

[a] Data presented as least square means with carcass weight used as covariate.

[b] Statistical significance of feeding system (F), ST treatment (T) or the interaction (I = FxT) indicated by $^{+}$(P < 0.10), *(P < 0.05), and **(P < 0.01). Other effects were not significant (P > 0.10).

Table IV. 6. Dry matter, protein, fat and fatty acid composition of lean tissues in pigs administered ST or placebo under single and choice feeding systems

	Single feeding			Choice feeding				Statistical
Item	Control	ST	Withdrawal	Control	ST	Withdrawal	SEM	significance[a]
Dry matter, %	30.12	38.85	29.77	30.43	28.67	30.21	0.16	T**
Protein, %	19.43	20.32	19.54	19.57	20.56	19.36	0.11	T**
Crude fat, %[b]	7.41	4.61	7.37	8.01	5.77	7.19	0.22	T**
SFA[c], %	37.91	33.22	36.57	38.71	35.07	37.94	0.33	F** T**
UFA[d]. %	61.74	66.24	63.08	60.99	64.29	61.71	0.24	F** T**
UFA/SFA	1.68	2.00	1.73	1.58	1.84	1.63	0.03	F** T**

[a] Statistical significance of feeding system (F), ST treatment (T) or the interaction (I = FxT) indicated by $^{+}$(P < 0.10), *(P < 0.05), and **(P < 0.01). Other effects were not significant (P > 0.10).

[b] as a percentage of lean.

[c] Saturated fatty acid as a percentage of lean.

[d] Unsaturated fatty acid as a percentage of crude fat.

Table IV. 7. Deposition rates (g/d) of dissected carcass tissues of pigs administered ST or placebo under single and choice feeding systems

	Single feeding			Choice feeding				Statistical
Item, g/d	Control	ST	Withdrawal	Control	ST	Withdrawal	SEM	siginificance[a]
Grower period (33-65 kg BW)								
Lean	354.7	400.5		328.6	366.7		13.0	
Fat	175.0	123.3		181.6	119.3		11.3	T^{**}
Bone	73.6	83.1		72.0	77.7		2.4	
Protein	62.8	67.8		58.0	64.2		1.6	T^{+}
Finisher period (65-100 kg BW)								
Lean	388.7	429.9	275.7	359.9	520.3	320.6	19.1	T^{**}
Fat	249.4	199.9	269.8	216.5	169.4	242.6	14.3	
Bone	74.8	94.6	50.5	74.7	92.5	70.4	3.8	T^{**}
Protein	65.3	81.9	45.4	68.2	106.5	53.3	4.1	F^{+} T^{**}
Whole period (33-100 kg BW)								
Lean	364.6	403.6	341.2	338.6	428.5	343.3	8.2	T^{**}
Fat	202.5	154.5	189.8	195.5	139.3	177.1	6.8	T^{**}
Bone	73.5	86.5	67.8	72.0	83.5	73.9	1.7	T^{**}
Protein	69.5	81.4	65.8	65.6	88.3	65.4	1.8	T^{**}

[a] Statistical significance of feeding system (F), ST treatment (T) or the interaction (I = FxT) indicated by $^{+}$(P < 0.10), *(P < 0.05), and **(P < 0.01). Other effects were not significant (P > 0.10).

Table IV. 8. Concentration of blood metabolites collected from pigs slaughtered at 100 kg BW 3 h after injection of ST or placebo under single and choice feeding systems

	Single feeding			Choice feeding				Statistical
Item	Control	ST	Withdrawal	Control	ST	Withdrawal	SEM	significance[a]
PUN, mg/dL	18.07	11.08	20.17	19.97	10.90	21.27	0.66	T^{**}
Glycerol, µg/m	4.55	5.87	3.26	4.58	6.19	3.59	0.37	T^{+}
Growth hormone, ng/mL	1.35	8.19	1.79	2.14	7.30	1.10	0.44	T^{**}
IGF-I, ng/mL	80.05	204.84	77.52	84.84	262.33	82.61	12.90	T^{**}
Insulin, ng/mL	1.34	1.63	1.03	1.38	2.54	1.09	0.13	T^{*}

[a]Statistical significance of feeding system (F), ST treatment (T) or the interaction (I = FxT) indicated by $^{+}$($P < 0.10$), *($P < 0.05$), and **($P < 0.01$). Other effects were not significant ($P > 0.10$).

V. FACTORS AFFECTING DIET SELECTION BY GROWING-FINISHING PIGS

A. INTRODUCTION

Kyriazakis (1989) suggested that when given a choice of two isoenergetic diets, differing in protein content, pigs have the ability to control their protein intake to meet their requirements. The results of Bradford and Gous (1991a and b) supported this observation. These researchers reported that growth of choice-fed pigs was not significantly different from pigs fed one diet. They also reported that dietary lysine intake was similar under both feeding systems. However, recent results in North America have shown that choice-fed pigs consumed significantly more protein/lysine than pigs assigned to a conventional two or three phase feeding regimen (Gourley et al, 1993; Nam and Aherne, 1994; Owen et al, 1994).

The difference in these results may have been caused by differences in the palatability of the diets offered in the choice feeding system (Emmans and Fisher, 1986). A~other possibility is that the pattern of diet selection, in a choice feeding system, may be affected by group size per pen (Walker, 1991; Gonyou et al, 1992; de Haer and de Vries, 1993). Thus, stocking density may influence the proportion of a high protein diet selected by pigs given a choice between high and low protein diets. However, there is little information on the effect of group size on diet selection of choice-fed pigs.

The objectives of these experiments were to 1) determine if differences in the palatability of low and high protein diets used in a choice feeding system would influence the pattern of diet selection of each diet and 2) to study the effects of stocking density (numbers of pigs per pen) on diet selection in two separate choice feeding experiments.

B. EXPERIMENTAL PROCEDURES.

Animals and treatments

Experiment 1: Seventy-two pigs, consisting of equal numbers of barrows and gilts (PIC Cambourough, Acme, Alberta), of an average initial body weight of 21.4±2.49 (SD) kg, were allotted in groups of three to each of 24 (1.2 x 2.3 m) totally slatted floor pens. Three pens of each sex were assigned to each of four treatments. The four dietary treatments consisted of 1) treatment 1; control, **C**, (conventional single feeding; 16.5% crude protein (CP), throughout the trial) and three choice feeding regimens: 2) treatment 2; choice between 18% and 12% CP diets (HP and LP), 3) treatment 3; choice between 18% and 12% CP diets with the addition of a feed flavour to the low protein diet (LPF), 4) treatment 4; as in treatment three but feed flavour added to the low protein diet only in the finisher period (LPFF). The composition of the experimental diets is shown in Table V.1. All diets contained 13.7 MJ DE/kg. The 18% CP and 12% CP levels were chosen to be above and below the pigs suggested requirement (NRC, 1988). Lysine, methionine, and threonine ratios were similar between the high and low protein diets. Sweet pig nectar (Prairie Microtech, Regina, Saskatchewan) was added to the low protein diet at the recommended level of 0.05% of the diet. Within each pen, choice-fed pigs had access to two single-hole feeders and pigs assigned to the single feeding regimen had access to one two-hole feeder.

Experiment 2: Sixty gilts and 30 barrows (PIC Cambourough, Acme, Alberta) of an average initial body weight of 20.2±1.85 (mean±SD) kg, were allotted in groups of 1, 3 or 6 to each of 27 totally slatted floor pens. The gilt:barrow ratio was maintained at 2 to 1 within each treatment. Pigs were offered a choice of two diets containing 13.7 MJ DE/kg and 20 or 12% CP (Table V.1). The protein levels were chosen to be above and below the pigs requirement (NRC, 1988). Each pen was assigned two single-hole feeders. Pen sizes were 1.2 x 1.5 m, 1.2 x 2.3 m, or 1.2 x 4.6 m for 1, 3, or 6 pigs, respectively, allowing 1.8 m^2 per pig for the individually penned pigs and 0.92 m^2 per pig for the other treatment groups.

Facility and diets

In both experiments, the room temperature was maintained at 20 to 22°C during the first 4 weeks, and 17 to 20°C thereafter and water was provided ad libitum from nipple drinkers. In both experiments, the position of the feeders within pens assigned to choice feeding was not changed throughout the experiment, as it has been reported that feeder position does not affect diet selection by pigs (Kyriazakis, 1989). The position of the two feeders, however, was randomized across pens. To accustom pigs to the diets, choice-fed pigs were allowed access to each diet on alternate days for 7 days prior to the commencement of the experiment as suggested by Kyriazakis (1989). Individual pigs weight gain and pen-based feed intake were recorded weekly. All diets were based on wheat, barley and soybean meal and contained sufficient vitamins and minerals to meet or exceed the pig's requirement for growth (NRC, 1988). Diets were fed in mash.

Chemical analysis

Diets were assayed for CP (N x 6.25) by Kjedahl method (AOAC, 1990). Separation and quantification of amino acids was accomplished with a High Performance Liquid Chromatography (Varian 5000, Varian Associates Inc., Walnut Creek, CA 94598) and a Varian Fluorichrom detector (excitation 340 nm, emission 450 nm). Each sample (0.1 g) was hydrolyzed with 3 mL of 6N HCl for 24 hr at 110°C. Samples were mixed 1:1 with the fluoraldehyde reagent prior to injection, then 25 µL of mixed sample was injected onto a Supelcosil 3 micron LC-18 reverse phase column (4.6 x 150 mm; Supelco, Oakville, ON).

Carcass data collection

Pigs were slaughtered at 105 kg liveweight. Fat depth and muscle depth were measured between the 3rd and 4th last ribs, 70 mm from the carcass mid-line, using a Hennessy Grade Probe (Hennessy and Chong Ltd., Auckland, New Zealand). Lean yield was estimated using the following equation (Agriculture Canada 1986); Lean yield = 54.31 - 0.36 (Fat depth, mm) + 0.06 (Muscle depth, mm).

Statistical Analysis

All data were analyzed by ANOVA using the GLM procedure appropriate for a randomized block design (SAS, 1985). One pig from the control group, and one from treatment of HP vs LP choice group were removed from experiment 1 due to poor health. All data were analyzed using a two-way factorial analysis with fixed factors as dietary treatment and sex. Means of each treatment were compared using the Student-Newman-Keuls test for each variable. When initial body weight and carcass weight were noted to be significant ($P < 0.05$) in the model, they were used as covariates for analysis of growth performance and carcass measurements. Data for the pattern of diet selection in the choice-fed pigs were analyzed up to 12 wk because some pigs in each pen were removed for slaughter, resulting in disturbance of the social balance in the pen. Orthogonal polynomial contrasts were performed on dependent variables (growth performance and nutrients intake) to test for linear and quadratic effect of group size. Each pen was considered as an experimental unit in both experiments.

C. RESULTS

Experiment 1

Choice feeding and the addition of flavour to the low protein diet did not significantly influence weight gain and feed intake at any stage of growth or for the overall period (Table V.2). There was no significant difference in feed to gain ratio of pigs fed the control or choice-fed diets not supplemented with flavour. The addition of flavour tended to increase feed intake which resulted in a significant decrease in feed conversion efficiency in the grower (20 to 55 kg) and overall period.

As expected, barrows had a greater feed intake and faster growth rate than gilts in the finisher period (55 to 105 kg) and from 20 to 105 kg liveweight. Gilts had a superior feed to gain ratio than barrows from 55 to 105 kg ($P < 0.05$) and from 20 to 105 kg liveweight ($P < 0.01$). However, gilts on the choice-fed diets unsupplemented with flavour had poorer feed to gain ratios than barrows, which resulted in a significant interaction of sex and treatment in feed to gain ratio from 20 to 105 kg liveweight.

Protein and lysine intake and their utilization for weight gain were significantly greater for choice-fed pigs in the diets supplemented with flavour than for control pigs in the grower period but not in the finisher period (Table V.3). For the overall period, addition of flavour to the low protein diet caused poorer ($P < 0.05$) utilization of protein and lysine intake for weight gain, and increased ($P < 0.01$) lysine intake but not protein intake. Barrows consumed more protein and lysine ($P < 0.05$) than gilts for the grower and finisher periods. Over the entire period, barrows had inferior ($P < 0.01$) utilization of protein and lysine for weight gain than gilts ($P < 0.01$).

After we confirmed that there was no significant effect of sex on diet selection, the sex effect was removed from the model (Table V.4). The addition of flavour to the low protein diet throughout the experiment or only in the finisher period actually decreased ($P < 0.05$) the percentage of the low protein diet consumed relative to that of the high protein diet (Table V.4). Overall, pigs selected 87.4% high protein diet, with only a slight difference among choice-fed groups. There was no significant change in the ratio of high and low protein diet selected throughout the 12 weeks of the experiment (Table V.4). The overall protein content in the diets selected by choice-fed pigs was 16.86, 16.98, and 16.94%, for the 20 to 55, 55 to 105 kg and overall period, respectively. The control pigs were fed a 16.69% protein diet throughout the experiment. The addition of flavour to the low protein diet increased ($P < 0.05$) the protein level of the diet consumed compared with that of choice-fed pigs not supplemented with flavour during the finisher period and the overall period (Figure V.1). Protein content in the diet consumed by gilts was higher ($P < 0.05$) than that selected by barrows for the finisher period (Figure V.1).

All carcass measurements taken were not significantly influenced by dietary treatment or sex (Table V.5). However, gilts tended to have a higher grade index and less fat thickness than barrows.

Experiment 2

There was a linear decrease ($P < 0.05$) in growth rate and feed intake with an increase in stocking density at any stage of growth or for the overall period (Table V.6). A similar linear decrease was seen in protein and lysine intake (Table V.7). Feed to gain ratio was greater in individually penned pigs than for group housed pigs but the difference was significant only for the period from 20 to 55 kg liveweight and the overall period (Table V.6). There was a linear decrease ($P < 0.05$) in protein and lysine intake per unit gain with an increase in stocking density, at any stage of growth or for the overall period. (Table V.7).

There was no significant difference in the proportion of the high protein diet selected by individually penned pigs or for those in groups of three (Table V.8). However, the groups of six pigs per pen selected a significantly lower proportion of the high protein diet than other treatment groups. There was no significant change in the ratio of high to low protein diet selected throughout the 12 weeks of the experiment for any treatment. The protein content (19.1%) in the diet selected by pigs housed in groups of three was greater ($P < 0.05$) than that (18.5%) of pigs penned in groups of six for the grower period (Figure V.2).

Individually penned pigs had greater ($P < 0.05$) lean yield and fat thickness than pigs housed in groups (Table V.9). All other carcass measurements taken were not affected by stocking density ($P > 0.05$).

D. DISCUSSION

Experiment 1

Previous studies using flavour supplementation have given pigs a choice of identical diets with or without flavour added (McLaughlin et al, 1983), or diets that were isonitrogenous but were based on different protein sources (Baidoo et al, 1986). Under these circumstances pigs tended to consume more of the supplemented than the unsupplemented diet. In the current experiment, flavour was added to the low protein diet of a pair of diets to stimulate its intake. However, addition of feed flavour to the low protein diet of choice-fed pigs did not stimulate a larger intake of the low protein diet over that of pigs fed the unsupplemented low protein diet. In fact, intake of the low protein diet was reduced by the addition of feed flavour. It would appear that the pig's physiological need to balance its amino acid intake takes precedence over palatability. However, it is possible that even though this particular feed flavour enhances the feed intake of starter pigs (Baidoo et al, 1986), it is less attractive to more mature pigs. Even with the addition of a feed flavour, the low protein diet was less palatable than the high protein diet. However, the data suggest that palatability of the low protein diet was not a major factor in determining the proportion of each diet selected in a choice feeding system in which identical ingredients were used.

The observation that barrows had superior feed intake and growth rate but poorer feed conversion efficiency (Table V.2) than gilts is consistent with the results of most previous experiments (Mahan and Gaber, 1985; Cromwell et al, 1993; Hansen and Lewis, 1993). However, the sex difference observed for growth rate was not reflected in the proportion of the high and low protein diet selected (Table V.4).

The overall diet selected by gilts, in all treatment groups, contained higher levels of protein and lysine than the diet selected by barrows. Similar observations have been reported by Owen et al (1994).

Experiment 2

Although several reports in the literature have summarized the effects of group size, feeder space, and stocking density on social competition within pens, growth and behaviour of pigs, this trial is the first one to examine the effect of stocking density on the pattern of diet selection in choice-fed growing-finishing pigs. There was a linear decrease in feed intake and growth rate with an increase in group size from 1 to 6 pigs per pen. (Table V.6). Chapple (1993) also reported a linear depression in both growth rate and feed intake with increasing group size from 1 to 5 pigs per pen. de Haer and Merks (1992), and de Haer and de Vries (1993) reported that group housed pigs ate more quickly, and ate more at each feeding bout but had fewer meals and lower intake per day than individually penned pigs. Hsia and Wood-Gush (1983, 1984) suggested that social facilitation in eating behaviour would induce an apparently satiated pig to consume additional feed, if a hungry pig was placed in an adjacent pen. This response was dependent on social rank, because more dominant pigs ate for longer and consumed more feed than less dominant pigs.

Feed to gain ratio decreased with an increase in stocking density in the present experiment. Gonyou et al (1992) and de Haer and de Vries (1993) observed faster growth rate in individually housed pigs than group housed pigs with no difference in feed intake and feed to gain ratio. Neilsen and Lawrence (1993) also reported little difference in performance when the number of pigs per pen was increased from 5 to 20. Also Petherick et al (1989) and Walker (1991) reported that larger groups had poorer feed conversion efficiency than smaller groups as a result of increased maintenance requirements, due to an increased activity in group housed pigs.

Pigs housed in groups of six selected less ($P<0.05$) of the high protein diet than pigs penned in groups of three (Table V.8). This may have been due to an increased level of activity and pig interaction within the pen. It is possible that dominant pigs monopolized the feeder containing the high protein diet and thus restricted protein intake of less dominant pigs (Hansen, 1977; Hansen et al, 1982).

In both experiments, pigs selected approximately 80% of the high protein diet for each of the 12 wks of the experiment and this was consistent across all treatments, irrespective of flavour addition to the low protein diet (Expt. 1) or different pig number per pen (Expt. 2). This result was similar to that of our previous experiment (Nam et al, 1994) but was not in agreement with the results of Kyriazakis et al (1990 and 1991), Bradford and Gous (1991a), and Kyriazakis et al (1991) who reported that the proportion of the high protein diet selected by choice-fed pigs decreased with time.

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Table V. 1. Composition of diets used in experiments 1 and 2 (as-fed)

Items	Experiment 1				Experiment 2	
	Control	Choice Treatments			High protein	Low protein
		High protein	Low protein	Low protein+flavor		
Ingredients (g/kg)						
Wheat	304.7	260	240.4	240.5	410	400
Barley	476.3	487.8	672.8	672.3	290	494
Soybean meal (46% CP[1])	151.4	184.4	-	-	240	29
Tallow	30	30	45	45	26	40
Limestone	11	11	11	11	13	14
Dicalcium-phosphate	12	12	14	14	7	8
Salt	4	4	4	4	4	4
Vitamin-mineral premix[2]	10	10	10	10	10	10
Lysine-HCl	0.6	0.8	2.9	2.9		0.5
Sweet pig nectar[3]	-	-	-	0.5		
Nutrients (As fed basis)						
DE[4], MJ/kg	13.70	13.70	13.70	13.70	13.70	13.70
Protein, %	16.69	17.76	11.98	11.97	19.96	12.06
Lysine, %	0.82	0.92	0.57	0.57	1.04	0.50
Methionine+cystine[4], %	0.53	0.55	0.39	0.39	0.62	0.42
Threonine, %	0.55	0.59	0.34	0.34	0.63	0.38
Calcium[4], %	0.72	0.72	0.71	0.71	0.73	0.73
Phosphorus[4], %	0.63	0.63	0.61	0.61	0.69	0.64

[1] Crude protein.

[2] Vitamin mineral premix supplied the following per kg of diet: 5,000 IU vitamin A, 500 IU vitamin D, 40 mg vitamin E, 30 μg vitamin B_{12}, 12 mg riboflavin, 45 mg niacin, 25 mg pantothenic acid, 300 mg choline, 5 mg Ethoxyquin, 150 mg Fe, 20 mg Mn, 120 mg Zn, 20 mg I, 20 mg Cu, .3 mg Se.

[3] Prairie Microtech, Regina, Saskatchewan.

[4] Calculated values.

Table V. 2. Performance of pigs fed a single diet or a choice of high and low protein diets with or without flavor[1] (Experiment 1)

Body weight, kg	Control		HP vs LP[2]		HP vs LPF[2]		HP vs LPFF[2]		SEM[2]	Probability[3]		
	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows		T	S	T x S
20-55												
Weight gain, g/d	724	756	749	875	785	779	812	815	33.3	NS	NS	NS
Feed intake, kg/d	1.73	1.87	1.77	2.02	1.96	2.27	1.95	1.96	0.11	NS	*	NS
Feed/gain, kg/kg	2.40	2.47	2.36	2.32	2.50	2.92	2.40	2.42	0.09	**	NS	NS
55-105												
Weight gain, g/d	833	875	846	954	876	943	891	893	31.5	NS	*	NS
Feed intake, kg/d	2.43	2.95	2.55	2.90	2.50	2.79	2.48	2.71	0.14	NS	**	NS
Feed/gain, kg/kg	2.91	3.36	3.02	3.05	2.85	2.97	2.78	3.04	0.12	NS	*	NS
20-105												
Weight gain, g/d	795	815	789	910	824	845	850	859	27.8	NS	*	NS
Feed intake, kg/d	2.14	2.47	2.21	2.50	2.28	2.56	2.24	2.39	0.07	NS	**	NS
Feed/gain, kg/kg	2.70	3.03	2.80	2.76	2.77	3.04	2.64	2.78	0.06	*	**	*

[1] Data are means of three replicates of three pigs each. Average initial body weight was 21.4 kg.

[2] HP:high protein; LP:low protein; LPF:low protein with a flavor throughout trial; LPFF:low protein with a flavor for only finisher period.

[3] Standard error of the mean, n = 3.

[4] T:treatment, S:sex, T x S:treatment x sex, NS:not significant, **:$P<0.01$, *:$P<0.05$.

Table V. 3. Dietary protein and lysine intake and their utilization for weight gain in pigs fed a single diet or a choice of high and low protein diets with or without flavor[1] (Experiment 1)

Body weight, kg	Control		HP vs LP[2]		HP vs LPF[2]		HP vs LPF[2]		SEM[3]	Probability[4]		
	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows		T	S	T x S
20-55												
Protein intake, g/d	286	314	299	340	339	385	321	327	19.5	*	*	NS
Protein intake/gain, g/kg	401	410	390	397	418	504	411	399	14.1	**	NS	NS
Lysine intake, g/d	14.1	15.5	15.5	17.6	17.5	19.9	16.6	16.9	0.99	*	*	NS
Lysine intake/gain, g/kg	19.7	20.2	20.1	20.5	21.6	26.0	21.2	20.6	0.73	**	NS	NS
55-105												
Protein intake, g/d	402	495	443	465	440	472	416	465	26.5	NS	*	NS
Protein intake/gain, g/kg	485	562	517	492	492	506	477	518	20.1	NS	NS	NS
Lysine intake, g/d	19.8	24.3	22.9	24.0	22.7	24.4	21.6	24.0	1.34	NS	*	NS
Lysine intake/gain, g/kg	23.8	27.6	26.7	25.4	25.4	26.2	24.7	26.8	1.03	NS	NS	NS
20-105												
Protein intake, g/d	355	414	378	410	396	435	377	405	14.6	NS	**	NS
Protein intake/gain, g/kg	450	505	469	459	468	523	456	468	11.4	*	**	*
Lysine intake, g/d	17.5	20.4	19.5	21.2	20.5	22.5	19.5	20.9	0.75	*	**	NS
Lysine intake/gain, g/kg	22.1	24.8	24.3	23.7	24.2	27.0	23.6	24.2	0.59	*	**	*

[1] Data are means of four replicates of three pigs each. Average initial body weight was 21.4 kg.

[2] HP:high protein; LP:low protein; LPF:low protein with a flavor throughout trial; LPFF:low protein with a flavor for only finisher period.

[3] Standard error of the mean, n = 3.

[4] T:treatment, S:sex, T x S:treatment x sex, NS:not significant, **:P<0.01, *:P<0.05.

Table V. 4. The proportion of the high protein diet selected by choice-fed pigs[1]

Week	HP vs LP[2]	SD[3]	HP vs LPF[2]	SD	HP vs LPFF[2]	SD
1	88.4	10.40	90.1	12.53	83.3	15.91
2	84.2	5.60	85.8	8.76	85.9	7.80
3	75.6	12.66	86.6	13.81	78.3	15.44
4	87.1	7.53	86.5	13.50	84.5	8.63
5	91.0^a	5.97	92.8^a	5.87	81.8^b	8.96
6	87.0	7.81	90.8	6.63	88.4	8.10
7	85.9	10.24	88.2	7.75	90.6	6.44
8	80.2^a	7.52	88.8^b	7.69	93.2^b	4.62
9	77.1	13.79	83.7	12.42	90.8	6.77
10	90.4	7.00	90.9	7.72	89.8	6.89
11	90.2	10.83	91.9	6.91	91.9	5.19
12	78.5	28.96	94.1	8.14	95.3	4.87
Mean	84.4^a	3.65	89.6^b	2.30	88.3^b	2.66

[1] Data are means of six replicates of three pigs each. Average initial body weight was 21.4 kg.

[2] HP:high protein; LP:low protein; LPF:low protein with a flavor throughout trial; LPFF:low protein with a flavor for only finisher period.

[3] Standard deviation, n = 6.

[a, b] Means in the same row without a common letter in their superscript differ ($P < 0.05$).

Table V. 5. Carcass characteristics of pigs fed a single diet or a choice of high and low protein diets with or without flavor[1]

(Experiment 1)

Body weight, kg	Control		HP vs LP[2]		HP vs LPF[2]		HP vs LPFF[2]		SEM[2]	Probability		
	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows	Gilts	Barrows		T	S	T x S
Killing wt, kg	102.6	104.0	104.5	105.8	106.4	104.5	105.3	105.7	1.56	NS	NS	NS
Carcass wt, kg	85.9	81.9	82.7	83.7	85.0	82.6	82.0	83.1	1.48	NS	NS	NS
Lean yield, %	51.0	50.1	51.5	51.2	52.1	51.0	51.3	50.4	0.59	NS	NS	NS
Fat thickness, mm	18.6	19.6	15.9	17.5	14.0	17.2	16.6	18.7	1.19	NS	NS	NS
Lean depth, mm	57.2	48.0	50.5	52.8	49.1	48.8	50.3	47.5	1.68	NS	NS	NS
Grade index	103.0	106.1	109.0	107.4	109.3	107.7	108.3	106.5	1.53	NS	NS	NS

[1] Data are means of three replicates of three pigs each. Average initial body weight was 21.4 kg.

[2] HP:high protein; LP:low protein; LPF:low protein with a flavor throughout trial; LPFF:low protein with a flavor for only finisher period.

[3] Standard error of the mean, n = 3.

[4] T:treatment, S:sex, T x S:treatment x sex, NS:not significant, **:P<0.01, *:P<0.05.

Table V. 6. Performance of choice-fed pigs in different size groups[1] (Experiment 2)

Body weight, kg	Number of pigs per pen			SEM[2]	Polynomial contrast[3]	
	1	3	6		Linear	Quadratic
20-55						
Weight gain, g/d	908	840	818	21.2	**	NS
Feed intake, kg/d	2.27	1.97	1.88	0.06	**	NS
Feed/gain, kg/kg	2.51	2.34	2.30	0.06	*	NS
55-105						
Weight gain, g/d	940	912	872	31.5	**	NS
Feed intake, kg/d	3.25	2.92	2.82	0.09	**	NS
Feed/gain, kg/kg	3.47	3.24	3.25	0.10	NS	NS
20-105						
Weight gain, g/d	922	874	845	23.4	*	NS
Feed intake, kg/d	2.79	2.44	2.36	0.06	**	NS
Feed/gain, kg/kg	3.03	2.81	2.80	0.07	*	NS

[1] Data are means of nine replicates. Average initial body weight was 20.2 kg.

[2] Standard error of the mean, n = 9.

[3] **: $P<0.01$; *: $P<0.05$; NS: not significant.

Table V. 7. Dietary protein and lysine intake and their utilization for weight gain in choice-fed pigs in different size groups[1] (Experiment 2)

Body weight, kg	Number of pigs per pen			SEM[2]	Polynomial contrast[3]	
	1	3	6		Linear	Quadratic
20-55						
Protein intake, g/d	425	375	347	10.9	**	NS
Protein intake/gain, g/kg	469	447	425	9.8	**	NS
Lysine intake, g/d	21.8	19.4	17.7	0.57	**	NS
Lysine intake/gain, g/kg	24.0	23.1	21.7	0.49	**	NS
55-105						
Protein intake, g/d	583	531	498	16.4	**	NS
Protein intake/gain, g/kg	623	586	572	15.8	*	NS
Lysine intake, g/d	29.5	27.0	25.1	0.88	**	NS
Lysine intake/gain, g/kg	31.6	29.6	28.8	0.80	**	NS
20-105						
Protein intake, g/d	509	452	425	11.2	**	NS
Protein intake/gain, g/kg	552	519	503	11.5	**	NS
Lysine intake, g/d	25.8	23.1	21.5	0.60	**	NS
Lysine intake/gain, g/kg	28.1	26.5	25.4	0.57	**	NS

[1] Data are means of nine replicates. Average initial body weight was 20.2 kg.

[2] Standard error of the mean, n = 9.

[3] **: $P<0.01$; *: $P<0.05$; NS: not significant.

Table V. 8. The proportion of the high protein diet selected by choice-fed pigs in different size groups[1] (Experiment 2)

Week	Number of pigs per pen					
	1	SD[2]	3	SD	6	SD
1	78.4	17.11	76.6	16.22	72.4	12.47
2	83.6	19.11	83.8	9.51	80.4	6.02
3	86.8	16.28	88.9	7.64	84.2	3.86
4	78.3	25.61	92.2	6.93	86.3	5.44
5	94.0^{a}	6.71	93.9^{a}	5.82	81.2^{b}	5.67
6	96.6^{a}	4.23	93.8^{a}	4.36	87.0^{b}	5.68
7	84.6	18.53	90.9	8.95	82.2	6.94
8	91.2	10.20	91.7	7.09	84.3	8.83
9	90.2	14.17	84.9	12.20	75.4	14.22
10	81.6	18.69	90.1	5.30	77.5	10.38
11	66.7	14.89	62.3	15.07	69.8	12.03
12	73.1	19.04	75.1	11.36	69.3	14.20
Mean	82.1^{ab}	8.87	87.0^{a}	5.64	78.7^{b}	6.02

[1] Data are means of nine replicates. Average initial body weight was 20.2 kg.

[2] Standard deviation, n = 9.

[a, b] Means in the same row without a common letter in their superscript differ ($P < 0.05$).

Table V. 9. Carcass characteristics of choice-fed pigs in different size groups[1] (Experiment 2)

Body weight, kg	Number of pigs per pen			SEM[2]
	1	3	6	
Killing wt, kg	105.5	104.2	105.1	0.48
Carcass wt, kg	80.2	80.8	82.32	0.61
Lean yield, %	49.8[a]	51.5[b]	51.6[b]	0.39
Fat thickness, mm	19.9[a]	15.2[b]	15.7[b]	1.01
Lean depth, mm	46.1	45.3	50.3	2.13
Grade index	108	110	110	0.69

[1] Data are means of nine replicates. Average initial body weight was 20.2 kg.

[2] Standard error of the mean, n = 9.

[a, b] Means in the same row without a common letter in their superscript differ ($P < 0.05$).

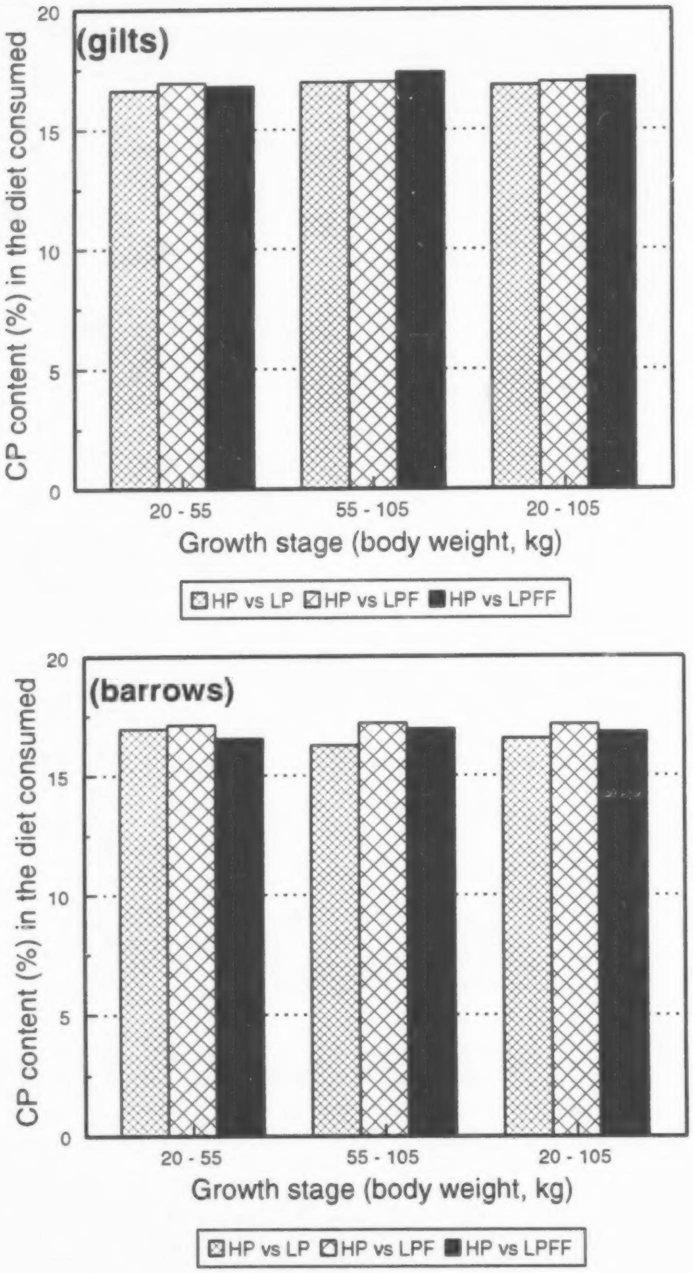

Figure V. 1. The dietary protein content (%) in the diet consumed by gilts and barrows in experiment 1 (treatment: $P < 0.001$, 55 - 105, and 20-105 kg; sex: $P < 0.05$, 55 - 105 kg).

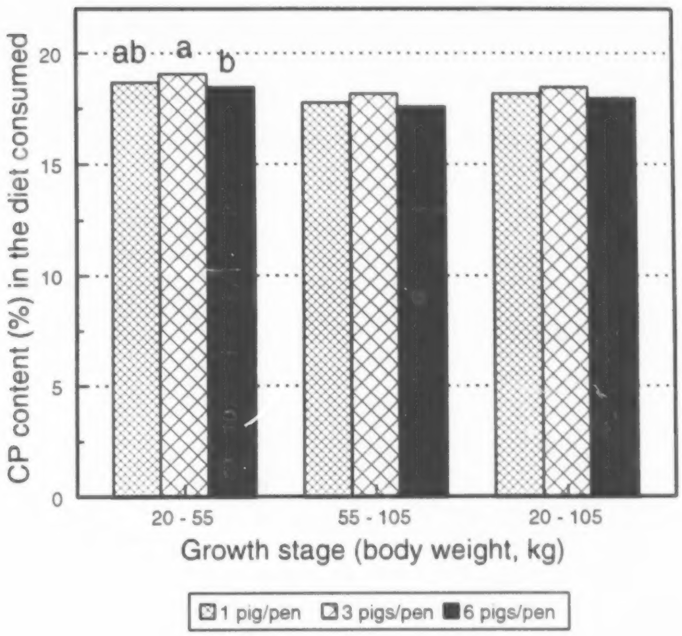

Figure V. 2. The dietary protein content (%) in the diet consumed by choice-fed pigs in experiment 2 (different letters represent a significant difference, $P < 0.05$).

VI. PRACTICAL ASPECTS OF FEEDING DIETS BASED ON IDEAL PROTEIN: EFFECTS ON PIG PERFORMANCE AND LEAN DEPOSITION

A. INTRODUCTION

Increasing demand of consumers for lean meat, combined with rising environmental concerns about nitrogen pollution from commercial piggeries, has forced pig researchers and producers to improve the efficiency of lean meat production through manipulating the feeding regimen. The efficiency of utilization of dietary protein is related to the quantity and quality of protein in the diet and its relation to dietary energy. There is a positive relationship between protein intake, the energy density of the diet and protein deposition in the pig (Campbell 1988).

'Ideal protein' is defined as a protein which contains amino acids in the exact proportion required by the pig and therefore gives maximum utilization of dietary protein (Fuller et al., 1989). After the ARC adopted this concept to describe the protein requirements of pigs in 1981, many attempts (Moughan and Smith, 1984; Moughan et al, 1987; Fuller et al, 1989; Wang and Fuller, 1989; Chung and Baker, 1992) were made to 'refine' or 'modify' the original amino acid ratio of ideal protein by using as the main criteria, nitrogen balance.

There are few practical experiments comparing the relative value of ideal protein to conventional protein in growing-finishing pigs. Yen et al (1986a, b) and Haydon et al (1989) conducted a growth trial to determine the ideal protein requirements of growing-finishing pigs by feeding different levels of dietary ideal protein based on total amino acid values instead of digestible amino acids. However, they did not include a conventional protein diet in their experimental treatments. Wang and Fuller (1990) showed that under practical conditions, a single pattern of amino acids would support both maintenance and growth efficiently. Amino acid supplements increase the cost of a diet and formulating a diet to balance all amino acids in an ideal protein may be uneconomical and impractical. Pig diets are usually grain based and supplemented with soybean meal and/or other protein sources to attain the required protein level. Amino acid supplementation of barley-based diets is needed to achieve an ideal pattern of amino acids but the amounts of individual amino acids added to the diet may vary from the ratio observed in studies using purified ingredients.

The objectives of the present experiment were 1) to evaluate the relative value of diets based on crude or ideal protein, 2) to determine whether it is necessary to balance for all or only a few amino acids (for example, lysine, methionine, threonine, and tryptophan) in an ideal protein diet, and 3) to determine the effects of feeding an ideal protein diet in a single phase, or three phases for growing-finishing pigs by measuring growth performance, carcass characteristics, and dissected tissues deposition rate. The current experiment was reviewed by the Lacombe Research Centre Animal Care Committee to ensure adherence to Canadian Council of Animal Care guidelines.

B. MATERIALS AND METHODS

Animal Management and Diets

One-hundred and thirty-six pigs (68 barrows and 68 gilts) with an average initial live weight of 23±0.6 (mean±SE) kg were used. One hundred and twenty eight pigs were allotted by weight and separated by sex, in groups of four to 32 pens measuring approximately 3 m x 2.4 m (Lacombe Research Centre, Lacombe Alberta). Four dietary treatments were then assigned to the pens to provide a pen replication of four. The dietary treatments included: 1) a conventional protein diet fed in three phases (**Control**), 2) a diet completely balanced to an ideal protein (**IP**) ratio (Wang and Fuller, 1989) using digestibility coefficients reported by Southern (1991) and amino acid analysis of the ingredients and fed in three phases (**IP3**), 3) a diet in which the first four limiting amino acids (lysine, methionine, threonine, and tryptophan) were balanced to an IP ratio and fed in three phases (**IPP3**), and 4) a diet identical to that fed in the second phase in treatment **IP3** throughout trial (**IP1**). The three phases reflected the live weight ranges 23-50, 50-70 and 70-105 kg. All other nutrients met or exceeded those of NRC (1988). All diets contained the same energy level (3400 DE Kcal/kg) and were prepared in pellet form and fed ad libitum in two-hole feeders. Water was freely available via nipple drinkers. Weight gains were recorded every two weeks and at the time of a diet change in each growth phase. Feed intake was recorded weekly. The ingredient composition and amino acid composition of the experimental diets are presented in Table VI.1 and VI.2, respectively.

Blood collection and organ weight measurements

Blood samples (10 mL) were collected from each pig at the time of slaughter. After stunning, blood from the vena cava was collected into heparinized tubes. After centrifuging at 3,000 g for 15 min at 4°C, plasma fractions were stored at -20°C until analyzed for plasma urea nitrogen (PUN). Organs (kidney, heart, spleen and lung) and full gut were removed from the carcass and weighed immediately.

Chemical analysis

Crude protein of diets and muscle samples were analyzed by Kjeldahl method (AOAC, 1990). For amino acid analysis, approximately 0.1 g of sample was weighted into screw-capped test tubes and mixed with 3 mL of 6 N HCl. The tubes were flushed with nitrogen and then heated in an oven at 100°C for 24 h. The hydrolyzed samples were mixed with the internal standard, DL-amino-n-butyric acid, and centrifuged at 1,100 x g for 15 min at room temperature. The samples were analyzed according to the method of Jnes and Gilligan (1983) using a Varian 5000 HPLC system (Varian Associates, Sunnyvale, CA) with a reversed-phase column previously described by Dugan et al. (1989). Methionine and cysteine were determined as methionine sulphone and cysteic acid, respectively, after oxidation with performic acid. The oxidized samples were dried according to the procedure described by Dugan et al (1992), then hydrolyzed and analyzed in the same manner as the samples that were not oxidized. Tryptophan content of diet samples was analyzed after alkaline extraction as described by Miller (1967). Fat content was measured as total fat extracted from 4 g of dried muscle during a 10 min extraction at 105^0C in petroleum ether, using a Soxtec 1040 extracting system (Tecator Ltd, Hoganas, Sweden). PUN was measured using an enzymatic colorimetric method (Sigma Chemical, St. Louis, MO) on pooled samples (4 pigs/sample).

Carcass data collection

In addition to the eight pigs (four barrows and four gilts) dissected into lean, bone and fat to provide an initial estimate of body composition, all pigs were slaughtered in the Meat Research Centre, Agriculture Canada, Lacombe Research Centre when the pen average BW reached 105 kg. Pigs were held for 2h prior to slaughter. Pigs were weighed, then stunned electrically with a 400V charge for a period of 2-3 s, then shackled, exsanguinated, scalded and eviscerated. The warm carcass was then split into left and right halves after removal of the viscera and head. Hennessy Grade Probe (Hennessy and Chong Ltd., Auckland, New Zealand) measurements were taken at the 3rd to 4th last rib, 70 mm from the carcass midline. Fat and muscle depths were recorded and used to predict lean yield. Lean yield content was estimated using the following equation (Agriculture Canada, 1986); Lean yield (%) = 54.31 - 0.36 (fat depth, mm) + 0.06 (muscle depth, mm). Maximum fat thickness was also measured on the mid-line of the carcass at the shoulder, 10th rib, loin and lumbar position. Warm carcass weight was calculated from the sum of the warm untrimmed carcass halves and the head, feet, tail, kidneys and kidney fat. Dressing percentage was calculated as the warm carcass weight(kg)/plant liveweight(kg)*100. Carcasses were then chilled for 24h at 1°C. After 24h, the left sides were then broken into the four primal cuts (shoulder, butt, ham and loin) and separated into fat, lean and bone following the procedures of Martin et al. (1981). Samples of lean were collected from each pig between the 6th and 10th ribs for analysis of the crude protein and fat content. Lean deposition efficiency was calculated from cutout data.

Statistical Analysis

Performance and carcass data were analyzed using a completely random design in a 4 x 2 factorial arrangement. Diet and sex represented the two main factors. Pen was used as the experimental unit providing a replication of four. One gilt from **IPP3**, one barrow from **IP3** and one gilt from control were removed from the data set due to the health problems and treated as missing values. Analysis of variance (GLM procedures in SAS, 1985) was used to test all main and interaction effects with a $P < 0.05$ indicating significance. Orthogonal contrasts were used to compare treatment means in this experiment. The comparisons made were C versus **IP3**, **IPP3**, and **IP1**; **IP1** versus **IP3** and **IPP3**; **IP3** versus and **IPP3**. Initial body weight and carcass weight were used as covariates for growth performance and carcass characteristics, respectively when appropriate.

C. RESULTS

The performance of pigs fed diets based on crude protein or on IP are presented in Table VI.3. From 20 to 50 kg BW and 50 to 70 kg BW, pigs fed the control diet had a higher ($P < 0.05$) intake of lysine, grew faster ($P < 0.05$) and had better ($P < 0.05$) feed to gain ratio than pigs fed IP diets. Within the ideal protein treatments single phase feeding (**IP1**) resulted in lower ($P < 0.05$) weight gain and a poorer feed to gain ratio than either phase fed IP treatment (**IP3** or **IPP3**) from 20 to 50 kg BW but there were no significant differences in performance between **IP3**, **IP1** and **IPP3** treatments from 50 to 70 kg BW. **IP1** pigs consumed less ($P < 0.05$) dietary lysine than **IP3** or **IPP3** pigs. Across all treatments, barrows grew faster ($P < 0.05$) and ate more ($P < 0.01$) feed and consequently more lysine than gilts, but there was no significant sex difference in feed to gain ratio. Growth performance was not significantly affected by dietary treatments or by sex during the period from 70 to 105 kg BW except that control pigs had better ($P < 0.05$) feed to gain ratio than **IP3**, **IPP3**, or **IP1** pigs and **IP1** pigs had higher ($P < 0.05$) lysine intake than the other pigs. Over the entire experimental period, control pigs had better ($P < 0.01$) weight gain and feed efficiency than all other treatment groups. **IP1** fed pigs had poorer ($P < 0.05$) feed to gain ratios than three phase fed pigs (**IP3** or **IPP3**). Barrows showed overall greater ($P < 0.01$) weight gain, feed intake and lysine intake than gilts. Formulating IP on the basis of 9 (**IP3**) versus 4 (**IPP3**) dietary essential amino acids did not affect any performance parameters during any of the growth periods.

There were no significant differences in carcass characteristics between any of the dietary treatments (Table VI.4). However, gilts typically had greater ($P < 0.001$) lean yield and thinner ($P < 0.001$) fat thicknesses than barrows when measured by Hennessy probe. Actual dissected lean yield tended to be greater in gilts than barrows but the difference was not significant. Hennessy probe measurement consistently overestimated lean yield percentage in all animals compared with dissected lean yield (49.3% vs 42.4%). Barrows were fatter ($P < 0.01$) than gilts at the 10th rib and lumbar positions (28.4 vs 25.2mm). There were no significant differences in composition of the prime cuts between any dietary treatments. Gilts had greater ($P < 0.01$) total lean in the prime cuts than barrows. There were no significant differences between sexes for fat or bone composition of prime cuts (Table VI.5). Control pigs had less ($P < 0.05$) total bone than pigs in ideal protein treatments.

The kidney was the only organ to show a significant difference in proportional size between dietary treatments (Table VI.5). Kidneys from control pigs were proportionally larger ($P < 0.05$) than those from other pigs. There was no significant difference in organ weight between barrows and gilts.

Muscle samples from control pigs contained more ($P < 0.01$) crude protein than those from other pigs (Table VI.6). Crude protein content of muscle from barrows was greater ($P < 0.05$) than that of gilts. Intramuscular fat content was not different across dietary treatments or sexes except that intramuscular fat content of **IP3** pigs was lower ($P < 0.05$) than that of **IPP3** pigs. Control pigs had higher ($P < 0.001$) blood urea nitrogen (PUN) concentration than **IP3**, **IPP3**, or **IP1** pigs. There was no significant difference in PUN concentration within the ideal protein treatments. Higher PUN levels were observed ($P < 0.05$) in barrows than in gilts.

Sex of pig had no significant effect on dissected lean and fat tissue deposition rates or feed to lean gain ratio or lysine to lean gain ratio but gilts deposited bone more rapidly ($P < 0.01$) than barrows (Table VI.7). Control pigs had faster ($P < 0.001$) lean deposition rates and required less ($P < 0.05$) feed per unit gain of lean than pigs fed IP diets. Control pigs also deposited fat more rapidly ($P < 0.05$) than other pigs. There was no significant difference in lysine to lean gain ratio between different dietary treatments.

D. DISCUSSION

In the current experiment, pigs fed a diet based on conventional crude protein clearly outperformed pigs fed any of the ideal protein feeding regimens. The increased performance was likely a result of more dietary crude protein (2 to 3%) in the control diet when compared with the **IP** diets. This suggests that total crude protein in the **IP** diets was insufficient to support optimum performance at the feed intake levels observed in this experiment. Since essential amino acids were present in adequate amounts in the **IP** diets, it may be that these diets contained insufficient non essential amino acids (Kies et al, 1992) . However, it is also possible that the high level of lysine added to these diets caused acidity by increasing the Cl^- content. It has been shown that lower dietary electrolyte balance depressed weight gain and feed intake of pigs (Patience et al., 1987). Calculated IP levels of the experimental diets were 12.7, 11.1 and 9.9% for 20 to 50 kg, 50 to 70 kg and 70 to 105 kg BW, respectively. This IP level for 20 to 50 kg BW was lower than the requirement (14.8% ideal protein) for weight gain from 25 to 55 kg BW, suggested by Yen et al (1986a). In the finisher period of this trial (70 to 105 kg BW), the protein levels in the ideal protein diets were close to the suggested dietary ideal protein level (10%) reported by Yen et al (1986b) and supported similar growth rates to that of pigs fed control diets (Table VI.3). Stranks et al (1988) suggested through simulation study that pigs at 35, 55 and 75 kg BW required ideal protein levels of 16, 13 and 10.7%, respectively, which were close to the values suggested Yen et al (1986a, b). Haydon et al (1989) reported that increasing the ideal protein level but maintaining a constant level of crude protein in diets resulted in linear and quadratic improvements in weight gain of gilts and barrows, respectively but not in the finisher period and this is in agreement with our results. In a recent trial (Lopez et al, 1994), there was no significant difference in growth performance of finisher pigs fed conventional or IP based diets.

Although pigs require the same ratio of amino acids in ideal protein throughout growth (ARC, 1981; Wang and Fuller, 1989), the poorer performance of the single phase feeding (treatment **IP1**) suggested that the ideal protein level in this experiment was too low for 20 to 50 kg BW pigs. Young pigs from 20 to 50 kg BW were unable to compensate for this by consuming extra feed and hence weight gain of **IP1** pigs in period one was reduced compared with pigs on the other treatments. From 70 to 105 kg BW, pigs in the **IP1** treatment tended to increase their lysine intake ($P < 0.01$) compared with other ideal protein fed pigs (**IP1** or **IP3**) in an attempt to make compensatory weight gain but growth rate was only similar to the that of pigs in the other treatments (Table VI.3).

Despite differences between dietary treatments in growth performance, there were no effects on carcass characteristics or in the chemical compositions of the prime cuts. Lopez et al (1994) also observed few differences in carcass characteristics between pigs fed conventional crude protein or IP diets. These researchers also observed that when feeding **IP** diets, carcass fatness was reduced at high dietary lysine level (1.0%) but was increased at low dietary lysine level (0.6%) compared with that of pigs fed conventional diets. Previous work has suggested that pigs fed low protein diets produce fatter carcasses compared to pigs fed optimum or high levels of dietary protein (Noblet et al, 1987; Cromwell et al, 1993; Hansen and Lewis, 1993). The current experiment illustrated that this does not occur when the low protein diets are balanced for dietary essential amino acid.

Increased kidney weight in control pigs may be due to increased protein intake with resulting increased metabolic activity and increased protein turnover (Table VI.5). Pigs in treatment **IPP3** had greater levels of intramuscular fat than all the other treatment groups (Table VI.6). It is not known why this should have occurred. It is worth noting that feeding ideal protein diets balanced for nine essential amino acids resulted in less fatty meat than feeding of ideal protein based on four commercial available amino acids (treatment **IPP3**). This may have important consumer implications.

Eggum (1970) stated that net protein utilization is highly and inversely correlated with plasma urea nitrogen. Therefore, PUN can be used as a predictive indicator of protein quality and amino acid nutrition status in pigs (Brown and Cline, 1974). Based on this suggestion, the results of the present experiment would suggest that the protein in the control diet was being utilized less efficiently than the protein in diets **IP3**, **IPP3**, and **IP1**. However, as shown in Table VI.7, lysine was utilized more efficiently for lean gain in control pigs than in other pigs and this indicates that the high PUN concentration in control pigs may be due to their increased protein intake compared with other pigs. This suggestion was supported by the increased growth rate and lean gain in control pigs. Decreased PUN concentration of pigs fed IP diets was in agreement with results of Lopez et al, Yen et al (1986a, b) who also observed an increased PUN concentration with an increase in crude protein level in diets.

As reflected in weight gain (Table VI.3), lean and fat deposition rate was greater in control pigs than pigs in other treatments (Table VI.7). This resulted in more efficient utilization of feed per unit gain of lean in control pigs. In contrast to the present result, Lopez et al (1994) found no significant difference in carcass protein deposition rates between pigs fed conventional crude protein or IP diets. This suggests that the improved lean gain observed in the current experiment occurred mainly prior to 70 kg BW when ideal protein fed pigs were likely deficient in total dietary protein.

Because there were no interactive effects on performance and carcass characteristics between dietary treatments and sex (Table VI.3), barrows and gilts showed similar response to dietary treatments. Observed growth performance parameters in the current experiment were in agreement with previous findings of Mahan and Gaber (1985), Cromwell et al (1993) and Hansen and Lewis (1993) who reported higher feed intakes, faster growth rates and poorer feed efficiencies in barrows compared with gilts. The values for the carcass characteristics reported herein are in agreement with those of others who have reported higher lean yields in gilts (Hansson et al, 1975; Hansen and Lewis, 1993), thinner fat thickness at the site of the 10 th rib in gilts than barrows (Hansen and Lewis, 1993) and similar lean growth rates between barrows and gilts (Cromwell et al, 1993). It has been reported that gilts have longer carcass length (Yen et al, 1986b; Hansen and Lewis, 1993) and less dressing percentages than barrows (Froseth et al, 1973; Hansen and Lewis, 1993). But these results were not observed in this experiment (Table VI.4).

In conclusion, feeding IP diets did not improve pig performance or lean growth rates compared with feeding conventional crude protein based diets. Poor performance of ideal protein-fed pigs may be a result of insufficient dietary protein in the early phases of growth. Based on the growth performance results of pigs fed a completely balanced ideal protein (**IP3**) and pigs fed a partially balanced ideal protein (**IPP3**), partially balanced IP diets are more practical and more economical because the diets require fewer ingredients and can be balanced with commercially available synthetic amino acids (lysine, methionine, threonine and tryptophan). In theory, efficiency of lean meat production should be improved by feeding diets with a balanced or ideal protein. This was not observed in this study and therefore more research is needed to investigate the interaction between dietary inputs and efficiency of lean deposition.

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Table VI. 1. Composition of experimental diets

	Control			Treatment[1] IP3			Treatment[1] IPP3		
	Period[2]			Period			Period		
	1	2	3	1	2[3]	3	1	2	3
Ingredients, %									
Barley	25.65	31.02	36.8	31.13	27.48	21.5	33.11	39.2	38.38
Wheat	50.0	50.0	50.0	50.0	39.6	50.0	50.0	50.0	52.0
Soybean meal (46% CP[4])	17.2	11.4	5.2	2.2				2.0	
Canola meal				7.3	3.9		7.9		
Oats					10.0	9.3			
Oat Groats					9.7	10.0			
Tallow	3.4	3.8	4.1	5.0	5.0	5.0	4.7	4.6	5.4
Limestone	1.1	1.1	1.1	1.0	1.1	1.0	1.1	1.1	1.1
Dicalcium phosphate	1.2	1.2	1.2	1.4	1.2	1.3	1.2	1.2	1.2
Vitamin-mineral mix[5]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Salt	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Lysine-HCl	0.05	0.08	0.21	0.39	0.38	0.38	0.42	0.38	0.38
DL-Methionine				0.04	0.11		0.04		0.02
L-Threonine				0.14	0.13	0.12	0.13	0.12	0.12
Nutrients									
DE Kcal/kg[6]	3400	3400	3400	3400	3400	3400	3400	3400	3400
Protein, %	18.0	16.0	14.0	14.97	13.11	12.24	14.13	12.82	12.22

[1] IP3: Completely balanced ideal protein in 3 phases; IPP3: Partially balanced ideal protein in 3 phases.

[2] Period 1 (20 to 50 kg BW); period 2 (50 to 70 kg BW); period 3 (70 to 105 kg BW)

[3] This diet was fed pigs in treatment IP1 throughout trial.

[4] Crude protein.

[5] Vitamin mineral premix supplied the following per kg of diet: 5,000 IU vitamin A, 500 IU vitamin D, 40 mg vitamin E, 30 µg vitamin B_{12}, 12 mg riboflavin, 45 mg niacin, 25 mg pantothenic acid, 300 mg choline, 5 mg Ethoxyquin, 150 mg Fe, 20 mg Mn, 120 mg Zn, 20 mg I, 20 mg Cu, 0.3 mg Se.

[6] Calculated values.

Table VI. 2. The analyzed amino acid and the calculated digestible amino acid composition in the diets

	Treatment control			Treatment IP3			Treatment IPP3		
	Period[1]			Period			Period		
	1	2	3	1	2[2]	3	1	2	3
Total Lysine, %	0.90	0.77	0.70	0.89	0.77	0.69	0.88	0.76	0.69
Total Met + cys[3], %	0.59	0.54	0.49	0.54	0.47	0.42	0.53	0.47	0.43
Total Threonine, %	0.58	0.52	0.45	0.62	0.54	0.48	0.61	0.54	0.48
Total Tryptophan, %	0.25	0.22	0.19	0.19	0.17	0.14	0.18	0.16	0.14
Ile.Dig[4]. Lysine, %	0.77	0.66	0.61	0.77	0.66	0.61	0.77	0.66	0.61
Ile.Dig. Threonine, %	0.49	0.43	0.38	0.52	0.44	0.41	0.52	0.44	0.41
Ile.Dig. Tryptophan, %	0.22	0.19	0.16	0.15	0.13	0.12	0.15	0.14	0.12
Ile.Dig. Met + cys,%	0.52	0.48	0.43	0.47	0.40	0.37	0.47	0.40	0.37
Ile.Dig. Histidine, %	0.37	0.33	0.28	0.28	0.24	0.22	0.28	0.23	0.21
Ile.Dig. Isoleucine, %	0.65	0.56	0.48	0.47	0.40	0.37	0.46	0.39	0.35
Ile.Dig. Leucine, %	1.19	1.04	0.88	0.86	0.75	0.67	0.84	0.73	0.68
Ile.Dig. Valine, %	0.66	0.60	0.54	0.57	0.47	0.37	0.54	0.47	0.43
Ile.Dig.Phe + tyr[5],%	1.31	1.15	0.98	0.94	0.80	0.73	0.91	0.83	0.74

[1] Period 1 (20 to 50 kg BW); period 2 (50 to 70 kg BW); period 3 (70 to 105 kg BW).

[2] Diet fed pigs in treatment IP1 throughout trial.

[3] Methionine + cystine.

[4] Ileal digestible.

[5] Phenyalanine + tyrosine.

Table VI. 3. Performance of pigs fed diets based on a conventional crude protein or ideal protein[1]

Body weight, kg	Treatments[2]				SEM[3]	P[4]	Sex		SEM[3]	P[4]	Contrast		
	control	IP3	IPP3	IP1			Gilts	Barrows			(Control vs IP3, IPP3, IP1)	(IP1 vs IP3, IPP3)	(IP3 vs IPP3)
20-50													
Weight gain, g/d	804	702	698	633	26	0.001	676	743	19	0.017	0.024	0.048	0.913
Feed intake, kg/d	1.73	1.66	1.60	1.71	0.058	0.411	1.60	1.76	0.043	0.010	0.319	0.250	0.498
Lysine intake, g/d	15.4	14.8	14.3	13.1	0.49	0.020	13.7	15.0	0.37	0.012	0.026	0.022	0.480
Feed/gain, kg/kg	2.16	2.37	2.31	2.74	0.092	0.001	2.29	2.39	0.068	0.989	0.006	0.002	0.644
50-70													
Weight gain, g/d	1074	981	935	993	38	0.095	916	1076	29	<0.001	0.024	0.459	0.405
Feed intake, kg/d	2.59	2.47	2.40	2.64	0.089	0.211	2.32	2.73	0.066	<0.001	0.391	0.070	0.540
Lysine intake, g/d	19.7	18.8	18.2	20.1	0.68	0.210	17.6	20.7	0.50	<0.001	0.391	0.070	0.540
Feed/gain[5], kg/kg	2.41	2.52	2.58	2.68	0.075	0.095	2.54	2.56	0.056	0.800	0.038	0.155	0.615
70-105													
Weight gain, g/d	981	946	879	980	47	0.366	902	991	35	0.070	0.390	0.253	0.312
Feed intake, kg/d	2.76	2.80	2.73	3.02	0.139	0.451	2.71	2.95	0.103	0.104	0.569	0.147	0.689
Lysine intake, g/d	19.0	19.4	18.8	22.9	0.99	0.022	19.2	20.9	0.74	0.114	0.247	0.004	0.699
Feed/gain, kg/kg	2.81	2.98	3.13	3.10	0.113	0.169	3.02	2.99	0.084	0.815	0.047	0.759	0.337
20-105													
Weight gain, g/d	915	834	812	815	24	0.015	800	888	18	0.001	0.002	0.765	0.511
Feed intake, kg/d	2.31	2.26	2.20	2.37	0.070	0.411	2.16	2.41	0.050	0.002	0.624	0.094	0.685
Lysine intake, g/d	17.5	17.0	16.7	17.4	0.52	0.643	16.2	18.1	0.39	<0.001	0.379	0.425	0.660
Feed/gain, kg/kg	2.51	2.70	2.71	2.94	0.071	0.006	2.69	2.72	0.053	0.748	0.003	0.030	0.743

[1] Data are means of 8 and 16 replicates of four pigs each for treatment and sex, respectively. Average initial body weight was 23.2 kg.

[2] control: Conventional crude protein; IP3: completely balanced ideal protein diet fed in three phases; IPP3: partially balanced ideal protein diet fed in three phases; IP1: completely balanced ideal protein diet fed in single phase.

[3] Standard error of the mean.

[4] Probability.

[5] Treatment x sex interaction ($P < 0.05$). Values of gilts on treatment control to IP1 were, respectively; 2.26; 2.51; 2.60; and 2.87. Comparable values for barrows are 2.56; 2.54; 2.55; 2.50.

Table VI. 4. Carcass characteristics of pigs fed diets based on a conventional crude protein or ideal protein[1]

	Treatments[2]				SEM[3]	P[4]	Sex		SEM[3]	P[4]
	Control	IP3	IPP3	IP1			Gilts	Barrows		
Warm carcass wt[5], kg	76.2	76.3	76.2	76.0	0.07	0.054	76.1	76.3	0.05	0.017
Dressing percentage	80.4	81.2	81.1	81.2	0.40	0.510	81.2	80.8	0.29	0.327
Carcass length, cm	81.7	82.1	82.2	82.5	0.42	0.614	82.1	82.2	0.30	0.725
Hennessy probe										
Lean yield, %	49.4	49.5	49.3	49.0	0.20	0.340	50.0	48.6	0.14	<0.001
Fat thickness, mm	20.5	20.5	20.8	21.3	0.64	0.790	18.9	22.6	0.45	<0.001
Muscle depth, mm	44.1	43.0	42.1	40.5	1.33	0.291	42.7	42.1	0.93	0.659
Actual dissected										
Lean yield, %	46.8	48.2	47.1	47.8	0.69	0.476	48.1	46.9	0.48	0.104
Ruler fat, mm										
Shoulder	45.8	45.5	46.7	48.4	1.19	0.360	45.8	47.4	0.83	0.191
10th rib	27.1	27.2	26.7	26.4	1.07	0.953	25.2	28.4	0.74	0.005
Loin	35.0	34.4	33.6	33.8	1.08	0.820	33.3	35.0	0.76	0.124
Lumbar	27.1	25.7	25.4	25.6	1.15	0.709	24.1	27.8	0.80	0.003

[1] Data are means of 8 and 16 replicates of four pigs each for treatment and sex, respectively. Average killing weight was 99.8 kg.

[2] control: Conventional crude protein; IP3: completely balanced ideal protein diet fed in three phases; IPP3: partially balanced ideal protein diet fed in three phases; IP1: completely balanced ideal protein diet fed in single phase.

[3] Standard error of the mean.

[4] Probability.

[5] Comparsion of IP1 vs IP3 and IPP3 differs ($P < 0.01$).

Table VI. 5. Organ weight and composition of the prime cuts of pigs fed diets based on a conventional crude protein or ideal protein[1]

	Treatments[2]				SEM[3]	P[4]	Sex		SEM[3]	P[4]
	Control	IP3	IPP3	IP1			Gilts	Barrows		
Organ weight[5], %										
Kidney[7]	0.36	0.35	0.33	0.35	0.007	0.024	0.35	0.35	0.005	0.875
Heart	0.49	0.49	0.51	0.48	0.015	0.587	0.49	0.49	0.011	0.743
Liver	2.53	2.47	2.38	2.49	0.050	0.195	2.46	2.48	0.035	0.632
spleen	0.23	0.23	0.22	0.22	0.010	0.624	0.23	0.22	0.007	0.371
Lungs and trachea	2.35	2.35	2.14	2.08	0.119	0.274	2.18	2.28	0.083	0.377
Gut (full)	13.51	12.88	12.59	12.59	0.402	0.376	12.61	13.23	0.280	0.132
Composition of the prime cuts[6], kg										
Total lean	20.70	20.36	19.95	20.18	0.300	0.350	20.73	19.86	0.209	0.007
Total fat	10.68	8.89	9.20	9.19	0.767	0.351	9.44	9.54	0.534	0.889
Total bone[7]	2.73	2.90	2.90	2.86	0.061	0.177	2.87	2.83	0.043	0.494

[1] Data are means of 8 and 16 replicates of four pigs each for treatment and sex, respectively.

[2] control: Conventional crude protein; IP3: completely balanced ideal protein diet fed in three phases; IPP3: partially balanced ideal protein diet fed in three phases; IP1: completely balanced ideal protein diet fed in single phase..

[3] Standard error of the mean.

[4] Probability.

[5] Expressed as a proportion of warm carcass weight.

[6] Amount of left side of carcass.

[7] Comparsion between control and other ideal protein differ ($P < 0.05$).

Table VI. 6. Crude protein and fat content from muscle samples and blood urea concentration of blood of pigs fed diets based on a conventional crude protein or ideal protein[1]

	Treatments[2]				SEM[3]	P[4]	Sex		SEM[3]	P[4]	Contrast		
	Control	IP3	IPP3	IP1			Gilts	Barrows			(Control vs IP3, IPP3, IP1)	(IP1 vs IP3, IPP3)	(IP3 vs IPP3)
Crude protein, %	23.5	22.9	22.9	22.7	0.14	0.003	22.0	23.1	0.10	0.044	<0.001	0.639	0.522
IM[5] fat (wet basis), %	2.30	2.08	2.61	2.03	0.173	0.092	2.11	2.41	0.120	0.089	0.755	0.154	0.039
PUN, mg/dL	15.8	11.0	10.7	10.1	0.88	<0.001	11.1	12.8	0.58	0.043	<0.001	0.419	0.759

[1] Data are means of 8 and 16 replicates of four pigs each for treatment and sex, respectively. Average killing weight was 99.8 kg.

[2] control: Conventional crude protein; IP3: completely balanced ideal protein diet fed in three phases; IPP3: partially balanced ideal protein diet fed in three phases; IP1: completely balanced ideal protein diet fed in single phase.

[3] Standard error of the mean.

[4] Probability.

[5] Intramuscular.

Table VI. 7. Dissected tissue deposition rate and feed to lean gain ratio of pigs fed diets based on a conventional crude protein or ideal protein[1]

	Treatments[2]				SEM[3]	P[4]	Sex		SEM[3]	P[4]	Contrast		
	control	IP3	IPP3	IP1			Gilts	Barrows			(Control vs IP3, IPP3, IP1)	(IP1 vs IP3, IPP3)	(IP3 vs IPP3)
Lean, g/d	338	308	282	286	10	0.003	297	310	7	0.201	<0.001	0.506	0.090
Fat, g/d	250	192	188	185	21	0.119	192	216	15	0.270	0.018	0.833	0.886
Bone, g/d	59	59	54	54	2	0.160	60	53	1	0.004	0.148	0.210	0.183
Feed/lean, kg/kg	6.77	7.26	7.67	8.04	0.302	0.034	7.22	7.64	0.223	0.170	0.015	0.128	0.338
Lysine/lean, g/kg	52.4	56.3	59.3	61.1	2.33	0.061	55.6	58.9	1.71	0.157	0.379	0.425	0.660

[1] Data are means of 8 and 16 replicates of four pigs each for treatment and sex, respectively. Average initial body weight was 23.2 kg.

[2] control: Conventional crude protein; IP3: completely balanced ideal protein diet fed in three phases; IPP3: partially balanced ideal protein diet fed in three phases; IP1: completely balanced ideal protein diet fed in single phase.

[3] Standard error of the mean.

[4] Probability.

VII. GENERAL DISCUSSION AND CONCLUSIONS

Feed cost of growing-finishing pigs is the main factor determining profitability of commercial pig production. It is therefore important to maximize feed utilization by growing-finishing pigs. I approached this problem in two ways by investigating the feasibility of choice feeding and by assessing the potential of ideal protein based diets.

Many pigs are unable to express their genetic growth potential under conventional feeding systems. In conventional phase feeding (ARC, 1981; NRC, 1988), one protein level is fed throughout one period of growth eg. 20 to 50 kg. While this protein level may meet the average requirements for most pigs during this period, at the start of the period, protein will be deficient and at the end of the period protein will be in excess. Such systems are designed to meet the needs of the average pig and therefore fail to meet the requirements of the majority of pigs. If pigs were able to choose between diets with different protein contents to meet their own protein requirement then an alternative feeding system, choice feeding, would enable all pigs to express their growth potential by optimizing their protein intake.

My results show that protein intake of choice-fed pigs is inconsistent. In the experiment described in chapters 2, 3, and 5, choice-fed pigs ate significantly more protein than their single-fed counterparts. However, this increased protein intake did not result in increased growth rate or improved carcass quality. This increased protein intake of choice-fed pigs was not in agreement with the previous findings of Kyriazakis et al (1990 and 1991), and Bradford and Gous (1991a, b). On the other hand, the recent results of Owen et al (1994) and Cromwell et al (1994) support my observations. Gourley et al (1993) observed that the protein(lysine) intake of choice-fed pigs was similar during the grower period but higher during the finisher period compared with single-fed pigs. Disagreement between the results of different workers may be due to the different ingredient composition of diets offered and(or) differences in palatability, if any, between high and low protein diets (Emmans and Fisher, 1986). For example, Kyriazakis et al (1990 and 1991) and Bradford and Gous (1991a, b) included fish meal as a protein source and milk replacer and molasses were added to the high and low protein diets used by Kyriazakis et al (1990, 1991). Kyriazakis and Emmans (1993) suggested that the palatability differences between fish meal and soybean meal based diets may have contributed to the pigs selecting more of the high protein diet based on soybean meal than diets based on fish meal. In my experiments, the high protein diet contained more than 20% soybean meal whereas the low protein diet contained less than 5%. This may have resulted in increased palatability of the high protein diet and hence overconsumption of protein.

In chapter 4, choice-fed pigs ate less protein than single-fed pigs but there was no difference in growth rate and hence an increased efficiency of protein utilization for weight gain. In contrast to the other experiments, this experiment was conducted in a barn equipped with computerized electronic feeders. The electronic feeders allowed access to only one pig at a time. The feeders containing the high and low protein diets were widely spaced (3.0 m apart) whereas in the other experiments, they were side by side. Group size was bigger, 16 pigs versus 3 pigs in the other trials. In this trial, both high and low protein diets were supplemented with 10% commercial sugar. It may be that under these conditions, the dominant pigs were able to monopolize the high protein diet feeder so that other pigs could not access the feeder of their choice and hence were unable to optimize their protein intake.

In chapter 5, the effect of stocking density was investigated. Pens of 1, 3, or 6 pigs were choice-fed from two single hole feeders in a conventional grower barn. Under these circumstances, pigs housed in groups of six selected less ($P<0.05$) of the high protein diet than pigs penned in groups of three (Table V.8). These results may have been due to an increased level of activity and pig interaction within the pen (Hansen, 1977; Hansen et al, 1982). However, the stocking density did not affect the overall pattern of diet selection with all groups choosing more than 80% of the high protein diet irrespective of the group size per pen. Although it has been reported that group size, feeder space and stocking density affect social competition within a pen, performance and behaviour of pigs (Walker, 1991; Gonyou et al, 1992; Chapple, 1993; Neilsen and Lawrence, 1993), there was little information available about the effect of stocking density on diet selection of choice-fed pigs. In a study of eating behaviour, de Haer and Merks (1992), and de Haer and de Vries (1993) reported that group housed pigs ate more quickly, ate more at each feeding bout, but had fewer meals and lower intake per day than individually penned pigs. When one phase choice feeding (24 vs 10% CP throughout trial) was compared to three phase choice feeding (24/14, 22/12, and 20/10% CP for 20 to 50, 50 to 70, and 70 to 105 kg BW, respectively) there was no significant difference in overall performance nor in protein intake. Indeed, there was a trend towards increased efficiency of protein utilization for weight gain and reduced protein intake in non-phased choice fed-pigs. Pigs in phased choice feeding treatments increased their selection of the high protein diet whereas pigs in non-phased choice feeding regimens continued to reduce the proportion of high protein diet selected as they grew. This pattern of diet selection supports the suggestion of Kyriazakis et al (1990) that pigs select a majority of a diet which is nearest in nutrient content to their requirement. Therefore, as long as the diets offered contain protein levels above and below the pigs protein requirement there was no advantage to using a phased system when pigs were choice-fed.

In an attempt to remove the palatability effect of the high protein diet, isoenergetic and isonitrogenous diets were formulated. These were supplemented with either lysine or with a combination of lysine, methionine, and threonine. The overall consumptions of lysine- or amino acids- supplemented diet were 35.7 and 31.8% of total feed intake, respectively. This avoidance of the lysine supplemented diet may be due to an amino acid imbalance of the diet (Henry, 1985).

If animals are offered a choice of two diets, they will select a diet with a balanced pattern of amino acids in preference to one containing a disproportionately high amount of one or more indispensable amino acids (Harper and Peters, 1989). However, the addition of methionine, threonine and lysine did not increase the intake of the amino acid supplemented diet of choice-fed pigs. In both cases, pigs preferred the unsupplemented diets to the amino acid supplemented diets. This avoidance of the amino acid supplemented diets may have resulted from a change to the acid-base balance of the diets. Lysine supplementation increased the acidity of the diet by increasing the chloride level. Patience et al (1987) suggested that a dEB (dietary electrolyte balance) of less than 100 mEq depressed feed intake and pig performance. As shown in Table III.1, the amino acid supplemented diets had dEB of 89 to 90 mEq. Pigs given the choice of high and low protein diets avoided the low protein diet which had a dEB similar to that of the amino acid(s) supplemented diet (Table III.1). This observation further supports the hypothesis of an acid-base effect on diet selection of choice-fed pigs.

Another evaluation of choice feeding involved ST treated pigs (Chapter 4). ST treated pigs have an increased lean growth rate (Campbell et al, 1990; Goodband et al, 1993) and require a higher protein intake (Boyd and Krick, 1991). In this trial, increased lean growth rate of ST treated pigs did not stimulate choice-fed pigs to increase dietary protein intake. In fact, the choice-fed ST treated animals had a lower protein intake than single-fed pigs. As already discussed, electronic feeders were used in this experiment and distance between the two feeders (3m), and competition between pigs (16 pigs per pen) may have reduced accessibility to the high protein feed.

Feed flavour was added to the low protein diet in another attempt to increase its intake (Chapter 5). In previous studies using flavour supplementation, pigs were given a choice of identical diets with or without flavour added (McLaughlin et al, 1983), or diets that were isonitrogenous but were based on different protein sources (Baidoo et al, 1986). Under these circumstance, pigs tended to consume more of the flavour supplemented than the unsupplemented diet. Even though this flavour has been shown to increase feed intake of weaner pigs (Baidoo et al, 1985), it caused decreased selection of the low protein diet and hence a further increase in protein intake. Therefore, it appears that in growing-finishing pigs, intake of the low protein diet cannot be increased by adding flavour. Because growing-finishing pigs actually reduced their intake of the flavoured diet compared with that of pigs fed unflavoured diets, then a better strategy might be to add flavour to the high protein diet to see if this would reduce its intake. It would appear that the pig's physiological need to balance its amino acid intake takes precedence over palatability. However, our data suggests that palatability of the low protein diet is not a major factor in determining the proportion of each diet selected in a choice feeding system in which identical ingredients are used. The overall diet selected by gilts in all treatment groups contained higher levels of protein and lysine than the diet selected by barrows. Similar observations have been reported by Owen et al (1994).

The observations in this research indicate that pigs lack the ability to control their protein (lysine) intake to meet their requirement. In contrast, Kyriazakis et al (1991) reported that pigs had the ability of protein regulation on the long term and short term basis. Pigs increased feed intake as the protein content of diet was decreased (long term regulation) and consumed consistently higher amounts of diet when they had access to a low protein diet rather than to a high protein diet (short term regulation). Under conditions of choice between high and low protein diets, pigs selected a diet that met their protein requirement. In general, choice-fed pigs consumed excess protein compared to single-fed pigs without a corresponding increase in growth performance. Although Bradford and Gous (1991b) suggested that choice feeding appears to have more potential for commercial pig production than does conventional single feeding, our data and that of several other recent findings (Owen et al, 1994; Gill et al, 1994; Cromwell et al, 1994) suggest that choice feeding is still not a viable alternative to conventional feeding systems for cost-effective pig production.

Another way to improve the efficiency of lean production through diet manipulations is to apply the concept of ideal protein into diet formulation. As suggested by ARC (1981), the concept of an ideal protein is the amino acid profile which exactly match the pigs requirement at the tissue level, leading to the maximum utilization of dietary protein (Fuller et al, 1989). In contrast to this concept, pigs fed ideal protein diets had inferior growth performance and dissected lean, fat,and bone deposition rate to pigs fed conventional crude protein based diets. Across treatment, level of essential amino acid was adequate for requirement and therefore these results indicated the importance of sufficient supply of non essential amino acid for optimum growth performance (Kies et al, 1992). Previous findings of Haydon et al (1989) and Lopez et al (1994) who reported no improvement of growth performance in finisher pigs fed ideal protein based diets is in agreement with my result. There is no apparent benefits of performance in formulating ideal protein balanced completely compared with partially balanced ideal protein diet.

In conclusion, pigs are not able to control protein and(or) lysine intake to meet their requirements when offered a choice of isoenergetic diets differing in protein and(or) lysine content. Choice-fed pigs consumed more dietary protein with similar performance to single-fed pigs. Feeding ideal protein based diets to growing-finishing pigs resulted in poorer performance than pigs fed crude protein based diets. It is not necessary to formulate the completely balanced ideal protein diet and partially balanced with lysine, threonine, methionine and tryptophan, ideal protein diets could applicable in practice.

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